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Knowledge visualizations: a tool to achieve optimized operational decision making and data integration

Hudson, Paul C.

Monterey, California: Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

KNOWLEDGE VISUALIZATIONS: A TOOL TO ACHIEVE OPTIMIZED OPERATIONAL DECISION MAKING AND DATA INTEGRATION

by

Paul C. Hudson
Jeffrey A. Rzasa

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Thesis Advisor:	Dan Boger
Co-Advisor:	Arkady A. Godin
Second Reader:	Glenn R. Cook

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Utilizing the DSS to present visualizations based on OLAP cube integrated data allow decision-makers to rapidly glean information and build their situation awareness (SA). This yields a competitive advantage to the organization while in garrison or in combat. Additionally, OLAP cube data integration enables analysis to be performed on an organization's data-flows. This analysis is used to identify the critical path of data throughout the organization. Linking a decision-maker to the authoritative data along this critical path eliminates the many decision layers in a hierarchal command structure that can introduce latency or error into the decision-making process. Furthermore, the organization has an integrated SOP from which to rapidly build SA, and make effective and efficient decisions.

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KNOWLEDGE VISUALIZATIONS: A TOOL TO ACHIEVE OPTIMIZED OPERATIONAL DECISION MAKING AND DATA INTEGRATION

Paul C. Hudson
Major, United States Marine Corps
B.S., United States Naval Academy, 1999

Jeffrey A. Rzasa
Captain, United States Marine Corps
B.S., United States Naval Academy, 2005

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June 2015

Author: Paul C. Hudson, and
Jeffrey A. Rzasa

Approved by: Dr. Dan Boger
Thesis Advisor

Arkady A. Godin
Co-Advisor

Glenn R. Cook
Second Reader

Dr. Dan Boger
Chair, Department of Information Sciences Department

Dr. William Gates
Dean, Graduate School of Business

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LIST OF ACRONYMS AND ABBREVIATIONS

AAR	After Action Report
AO	Area of Operation
API	Application Program Interface
C2	Command and Control
C2ISR	Command and Control: Information, Surveillance, and Reconnaissance
CCIR	Commander's Critical Information Requirement
CDWA	Contextualized Data Warehouse Architecture
CMC	Commandant of the Marine Corps
COA	Course of Action
CONUS	Continental United States
COP	Common Operational Picture
CSV	Comma-Separated Value
CWM	Cognitive World Model
DBMS	Database Management System
DIKUW	Data, Information, Knowledge, Understanding, Wisdom
DOD	Department of Defense
DoS	Days of Supply
DSPL	Dataset Publishing Language
DSS	Decision Support Systems
DTD	Deployable Training Division
DWM	Digital World Model
EEI	Essential Elements of Information
EEFI	Essential Elements of Friendly Information
FFIR	Friendly Force Information Requirement

GCSS-MC	Global Combat Support System-Marine Corps
GPDE	Google Public Data Explorer
GSORTS	Global Status of Resources and Training System
GUI	Graphical User Interface
HDFS	Hadoop Distributed File System
HQMC	Headquarters, Marine Corps
HSI	Human System Interface
HVI	High-Value Individual
HVT	High-Value Target
HUMINT	Human Intelligence
IMINT	Imagery Intelligence
IS	Information System
IT	Information Technology
IV	Information Visualization
JSON	JavaScript Object Notation
KB	Knowledge Base
KDD	Knowledge Discovery in Databases
KV	Knowledge Visualization
MAGTF	Marine Air-Ground Task Force
MCDP	Marine Corps Doctrinal Publication
ML	Machine Learning
MOE	Measures of Effectiveness
OLAP	Online Analytical Processing
OODA	Observe-Orient-Decide-Act
ORION	On-road Integrated Optimization and Navigation
OSINT	Open-source Intelligence
Owl	Openwall GNU/*/Linux

PIR	Priority Information Requirement
PWM	Physical World Model
RDFS	Resource Description Framework Schema
R-cube	Relevance Cube
SA	Situation Awareness
SIGINT	Signals Intelligence
SOP	Shared Operational Picture
TCRI	Tactical Cloud Reference Implementation
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UPS	United Parcel Service
USMC	United States Marine Corps
XML	Extensible Markup Language

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I. INTRODUCTION

The overabundance of data created by modern information systems (IS) has led to a breakdown in cognitive decision making. Without authoritative source data, a commander's decision-making process is hindered as they attempt to paint an accurate shared operational picture (SOP) for their organization. Further impeding the decision-making process is the lack of proper interface interaction to provide a visualization that aids in the extraction of relevant data from the mass of unusable data (Keim, Mansmann, Schneidewind, & Ziegler, 2006, p. 1). In the United States Marine Corps (USMC), the communication breakdown between the Command and Control: Information, Surveillance, Reconnaissance (C2ISR) system and the Global Combat Support System-Marine Corps (GCCS-MC) impedes the decision-maker from perceiving an accurate SOP. As a result, the commander is not provided the most accurate data on which to base his or her decision. By providing the decision-maker with a decision support system (DSS) that utilizes visualization tools to present accurate and relevant data returns from an integrated knowledge base (KB), all echelons of operational and strategic decision-makers can achieve a SOP. With this SOP, organizational decision-makers can more efficiently and effectively advance through their decision-making processes.

A. PROBLEM AND PURPOSE STATEMENT

The decision-maker's cognitive capacity often limits the amount of data that they can assimilate before situation awareness (SA) deteriorates. With the aid of a DSS, data streams may be scalable to better meet the needs of the decision-maker. The automated processing of optimized interface visualizations with allocation recommendations will depict a real-time SOP throughout the organization. This SOP will reduce the latency and possible error injection points that exist in the current hierarchal command structure of USMC organizations.

The lack of data integration creates a saturated data pool that is unorganized, irrelevant, and redundant (Moody & Walsh, 1999). A visual interface that extracts relevant data from the mass of unusable data will help commanders quickly orient themselves to the situation and build a more accurate SOP (Keim, Mansmann, Schneidewind, & Ziegler, 2006). Furthermore, customizable queries will allow the user to display real-time data, integrated across applicable data sources, allowing for a scalable interface that meets the user's decision-making data requirements. According to Keen and Scott-Morton (1978), "the information system should be tailored to the information processing style of the individual user" (as cited in Sobol & Klein, 1989, p. 893). With rapid access to relevant and required data, the commander will be able to build a more accurate and reliable SOP that limits data saturation. The automated processing of optimized interface visualizations, with allocation recommendations, will transform the current hierarchal command structure decision making process from one that is reactive, to on that is predictive, and ultimately prescriptive. This transformation will yield an organizational competitive advantage both in garrison and in combat.

The purpose of this qualitative study is to develop the appropriate content from both the C2ISR and GCSS-MC data streams to allow the Marine Air Ground Task Force (MAGTF) commander and staff to make effective decisions based off the single incorporated data stream without outside resources. This research was conducted for Logistics Vision & Strategy Branch Headquarters, Marine Corps (HQMC) for incorporation into the C2ISR and GCSS-MC information technology (IT) solution.

B. RESEARCH QUESTIONS

This thesis seeks to answer the following questions:

1. What is the most efficient method to display real-time information from the operations, intelligence, and logistics online analytical processing (OLAP) cube database, in order to provide an accurate SOP to the decision-maker?
2. What is the relevant information from the OLAP cube database that is required by a MEF decision-maker in order to form an accurate COP?

C. METHODOLOGY

The initial research method approach used was a case study or review into the current tactics, techniques, and procedures (TTPs) of commanders regarding C2ISR and GCSS-MC. Selected observations and documentation from Marine Corps Center for Lessons Learned (MCCLL), debriefs, and after-action reports provide the baseline cases to retrieve the research data. The data analysis is grouped by themes for interpretation and correlation. A grounded theory research approach determines the data stream similarities between C2ISR and GCSS-MC. These similarities are important in the determination of optimization potential for GCSS-MC as a standalone analytical tool. This combined filtered data is the conduit for developing the interface dashboard utilizing a systems engineering approach. Based on operational expertise with no imposed constraints, the researcher developed a task sequence flow that shows what data should flow through the two incorporated systems—C2ISR and GCSS-MC—to the MEU Commander. This involved several trips to interact with C2ISR and GCSS-MC sponsors.

Secondary research provided the data and researchers consolidated it thematically from lessons learned materials. These data sets were analyzed by incorporating a ranking system to determine what data and information the commanders determined most useful, relevant, and important at each level of the command and staff structure. Then the best information practices were incorporated into a proposed solution to the data requirements necessary in the integration of the operational, intelligence, and logistics data streams for future commanders.

D. POTENTIAL BENEFITS AND LIMITATIONS

The potential benefit of this thesis study is the discovery of an enhanced data stream of information to the commander and staff. The data stream would contain the optimized portions of intelligence, operational, and logistics information available to the commander and staff via USMC database resources within the Department of Defense (DOD) architecture. When utilized in conjunction with available C2ISR and GCSS-MC data streams, database queries may enhance the combat capability of the force stemming from improvements in logistic agility. Further budgetary constraints within the DOD necessitate these cost-saving strategies of supply postures. Research was limited to functional assessments, but does not include OLAP design or data integration algorithms. Continued research developing the optimized COTS OLAP, which combines the C2ISR data stream with the GCSS-MC data stream in order to achieve the desired outputs developed in this research, will be necessary. In addition, assessing the collaborative planning capability enabled by suggested COTS OLAP decision support tools that integrate operations, logistics, and intelligence data is recommended.

II. LITERATURE REVIEW

A. USMC DOCTRINE

The conduct of warfare is as much an art form as it is a scientific process. The science comes into play as inputs create outputs and internal and external forces create reactions to situations. The artistic realm employs creativity during unique situations in order to devise practical solutions. The United States Marine Corps (USMC) relies upon doctrine to drive the scientific process, or tactics, techniques, and procedures (TTPs). The doctrine does not dictate rules, but instead creates a fabric of knowledge from which a commander can deviate based upon the warfighting tools available. According to General A. M. Gray, 29th Commandant of the Marine Corps (CMC), the fundamental nature of warfare is fluid and the means and methods used in implementation evolve (USMC, 1997a). General Gray warned that without constant improvement of our profession, the Marine Corps risks becoming “outdated, stagnant, and defeated” (USMC, 1997a, p. 6). General C. C. Krulak continued this acknowledgement of the evolutionary nature of warfare stating, “doctrine must continue to evolve based on growing experience, advancements in theory, and the changing face of war itself” (USMC, 1997a, p. 2). The drastic changes in warfare throughout history have resulted from disruptive technologies that ultimately upset the equilibrium in war, such as the rifled bore, railroad, wireless communication, and information technology.

1. USMC Warfighting Philosophy

War is a violent clash of wills between organized groups, characterized by the use of military force, including both state and non-state actors (USMC, 1997a). War’s essence is a “violent struggle between independent, irreconcilable wills, each trying to impose itself on the other” (USMC, 1997a, p. 3). The very nature of the conflict of opposing human wills, demonstrates the inherently interactive social process that makes up warfare. Despite the simplistic appearance of warfare, the conduct is extremely difficult due to countless factors, which when combined, manifest into the theory of friction. According to MCDP 1 (1997a), “friction is the force that resists all action and saps energy. It makes the simple difficult and the difficult seemingly impossible" (p. 14). Friction could be a result of indecisiveness and therefore mental in nature. Often self-induced, friction can be caused by numerous factors including lack of coordination, complex task organizations or command relationships, or complicated technologies. According to Clausewitz (1968), "Everything in war is simple, but the simplest thing is difficult. The difficulties accumulate and end by producing a kind of friction that is inconceivable unless one has experienced war" (p. 119).

Other significant attributes of war include uncertainty, fluidity, disorder, and complexity. Uncertainty, or the fog of war according to Clausewitz (1968), is the unknowns about the enemy, environment, and the friendly situation. Clausewitz (1968) continues that based on this uncertainty, all actions in warfare are founded on incomplete, inaccurate, and contradictory information. Based on the fluidity of war, the conduct of such actions requires flexibility of thought and no episode during the preparation or conduct of war can be viewed in isolation (Clausewitz, 1968). According to Clausewitz (1968), some portions of warfare will be dictated by periods of organized chaos and intense combat, while other periods may be saner, limited to information gathering alone. Disorder follows extreme occurrences of uncertainty, fluidity, and friction, which leads to instructions and information becoming unclear and misinterpreted, ultimately resulting in complete communication failure (Clausewitz, 1968).

MCDP 6 describes belligerents as a complex system of numerous individual parts, vice a singular opposing will, which the intricacy of warfare breaks down (USMC, 1996). However, according to MCDP 6, it is not the number of parts that makes a system complex, but instead the interactions of those parts (USMC, 1996). MCDP 6 also explains that military action is a complex system by nature and will exhibit unpredictable, chaotic behaviors that defy precise control. The unique, unpredictable nature of warfare composed of moral, mental, and physical forces drives situations that cannot isolate individual cause and effect, but instead are fundamentally characterized by their human nature (USMC, 1997a).

Operational objectives in warfare are achieved through military force in two general ways: annihilation and erosion. According to MCDP 1 (1997a), the strategy of annihilation embodies the temporary or permanent elimination of the belligerent as a viable military threat. Erosion, by contrast, convinces the enemy that accepting terms is beneficial to their personal interest vice the continuation of hostilities (USMC, 1997a). Military force is the deadliest element of national power at the discretion of the military decision-makers, but must be considered in concert with the other elements of military force: diplomatic, informational, and economical. MCDP 1 (1997a) defines the spectrum of conflict as an atmosphere spanning non-war military operations to general warfare. The military involvement and use of force required throughout this spectrum is broad, based on factors including overarching policy objectives, available military means, national will, and density of combat power (USMC, 1997a). In addition, there are three distinct hierarchical levels of war, interrelated with operations conducted within each layer simultaneously. These include: strategic, focusing on policy objectives; tactical, focusing on the application of combat power at a specific place and time; and operational, focusing between the two, using tactical results to attain strategic objectives (USMC, 1997a).

Different styles of warfare exist within the spectrum of conflict residing between annihilation and erosion. The U.S. Marine Corps (1997a) describes attrition as a direct test of strength; described as "the cumulative destruction of the enemy's material assets by superior firepower" (p. 36). In contrast to attrition is maneuver warfare, the principle focus of Marine Corps warfare doctrine, which circumvents problems and attacks from an advantageous position vice attacking the strength. Generally enemy concentrations are avoided and friendly strengths are used against enemy weaknesses to maximize advantages. This style relies heavily on identifying and exploiting enemy weaknesses and acting with tempo, using firepower and attrition to eliminate the enemy's center of gravity incapacitating them systematically.

Two concepts, both significant contributors to combat power and heavily dependent on information flow, are speed and focus. Speed consistent over time is tempo, which allows decision-makers to seize the initiative and dictate terms during combat. MCDP 1 (1997a) states that combat focus converges the effects of the coordinated efforts of ground combat, aviation, and combat service support elements in time and space on the objective for the accomplishment of mission goals. Implementation of the right amount of speed and focus achieves surprise derived from deception, ambiguity, and stealth. Strong situation awareness, founded from cognitive knowledge, leads to the exploitation of surprise based on bold action according to doctrine (USMC, 1997a).

Endsley (1995) stated "situation awareness is the perception of the elements in the dynamic environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (p. 36). In the case of the commander fulfilling a command and control function, situation awareness is dependent upon their ability to draw an accurate representation of the dynamic environment based on their interaction with the computer-based decision support system (DSS). The rapid and accurate building of situation awareness will aid the commander proceed through their decision-making process.

The decision-maker's situation awareness (SA) is derived from his or her interaction with the computer-based DSS, as depicted in the world models of DSS; Figure 1. This interaction drives a higher degree of situation awareness as it shapes the cognitive world model (CWM) of the decision-maker. The CWM is shaped as the decision-maker queries the DSS with information requests. These queries retrieve information from the digital world model (DWM), which is the correlated data from the sensors. Sensors are collecting data from the dynamic environment that makes up the physical world model (PWM). By minimizing the gaps between the CWM, DWM, and PWM, the user will have a more accurate shared operational picture (SOP). In order to minimize these gaps, there exists a requirement for a cognitive assistant to aid the decision-maker through predictive and prescriptive analysis of the DWM.

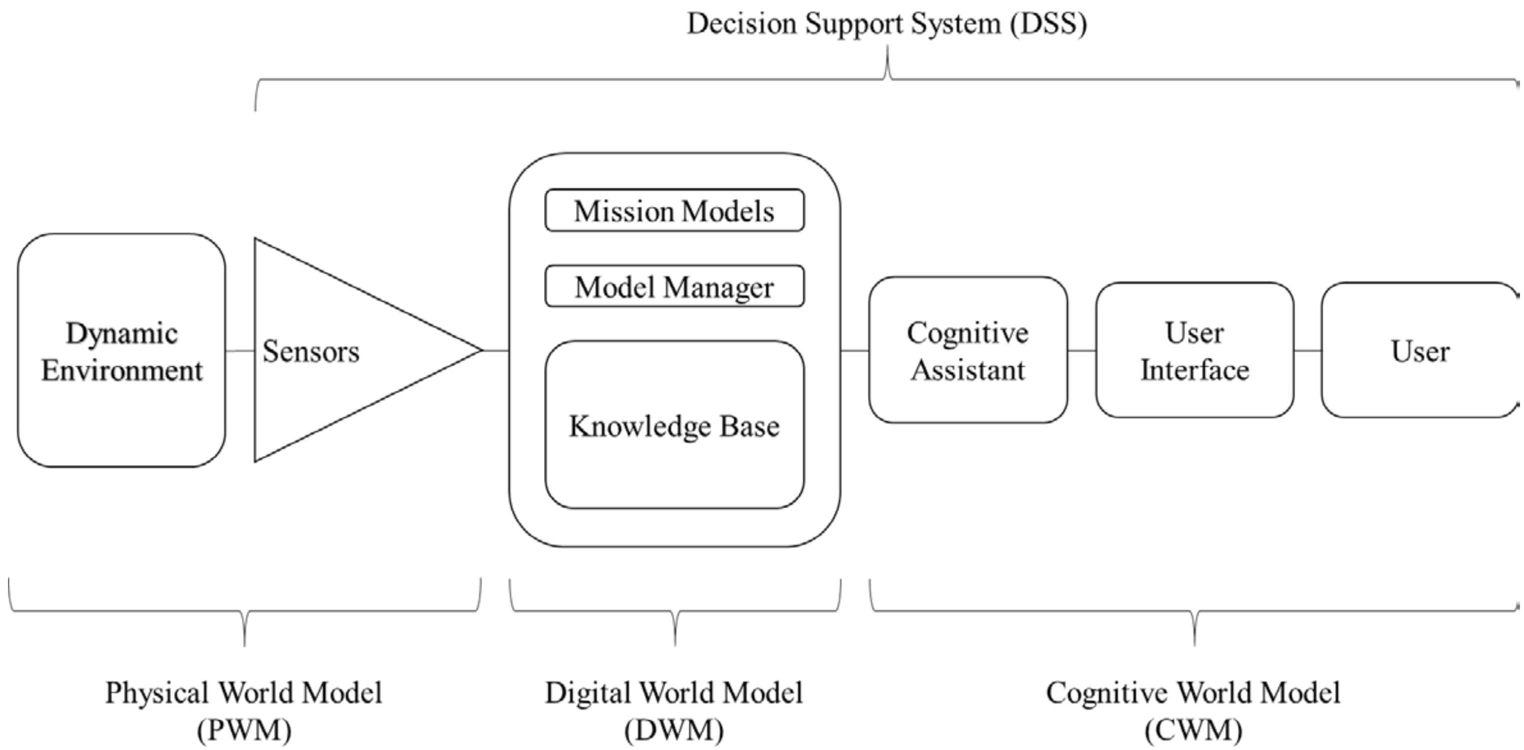

Figure 1. The World Models of the DSS

The dynamic relationships among the physical, moral, and mental components of an enemy are complex, and define the unique character of a belligerent force. Understanding which factors are critical and incapacitating to the enemy is important in order to define the center of gravity of the competing forces. In combination with understanding where the enemy is most vulnerable to attack, Commander's efforts should be focused toward affecting the aspects that are most impactful, the critical vulnerability, leading to the collapse of the belligerent force. Hans von Seeckt is quoted in MCDP 1 (1997a) "Intellect without will is worthless, will without intellect is dangerous" (p. 51).

2. The Role of Information

Marine Corps forces are task organized, adaptable units tailored for operations during a wartime environment consisting of the appropriate ground combat, aviation, support, and command element. The tasked organized units are built around the premise of the MAGTF. The MAGTF is a scalable and malleable in size and structure based upon the situation or crisis. The MAGTF is equipped with technology that is easily maintainable, reliable, and interoperable allowing for operation in undeveloped environments with minimal supporting infrastructure. "The overreliance on technology and the failure to make the most of technology capabilities" (p. 67) are two inherent dangers of newer equipment within the Marine Corps (USMC, 1997a). Information systems (IS) enhance warfighting by improving the commander's ability to wage war. Technology is a component of, not a substitution for, the commanders' decision-making process. IS are exposed in austere environments and commanders' dependencies on them create unacceptable vulnerabilities negated by the instructive commander's intent for operations. Advancements in technology are focused on making structured (static, rigid) TTPs into semi-structured TTPs that are adaptable to a dynamic environment. Instead, IS helps the different operational tiers within a unit function more efficiently by inducing greater data-to-decision capacity.

Information systems need to integrate within the Marine Corps command philosophy to achieve benefits and must drive the commander's actions based upon taking the initiative or reacting to the opponent (USMC, 2001). During the conduct of war, command and control is decentralized; subordinate commanders making decisions based on the intent of the senior commander. Information systems, combined with proper procedures, enhance command and control abilities and ideally support big data veracity, but must not detract or disallow from the human on-the-loop decision-making ability. Marine Corps commanders will place themselves in a physical or virtual position to influence combat, enabling observation of action directly and indirectly. For example, filtered unmanned aerial system (UAS) footage provides indirect observation, and circumvents delays and inaccuracies of information passage providing the decision-maker with a recognized information source. The C2 system should support the dictated veracity of the commander, allowing for updating of courses of action and ranked priorities.

The essential element of the conduct of warfare is decision-making at the appropriate level, and time is often the critical factor for effectiveness. Whichever commander makes and implements decisions quickest gains the decisive advantage during dynamic situations. Speed, however, is not as important during deliberate planning situations. At higher levels of command, decision-making is an analytical process based on a comparison of the information and the courses of action available. According to the Marine Corps (USMC, 1997a), the essence of the problems inherent with decision-making is selecting the best course of action with an acceptable level of risk quicker than your opponent. As stated in General George Patton's published memoirs (1979), "a good plan violently executed now is better than a perfect plan executed next week" (p. 354).

3. Commander's Critical Information Requirements

The commander's critical information requirements (CCIRs) are bits of information necessary for timely decision-making appropriate to the position within the spectrum of conflict (Joint Staff, 2011). This information identifies friendly and enemy activities as well as the environment deriving knowledge from data provided via the operational, intelligence, and logistics COP. It is imperative that CCIRs link to critical decisions the commander anticipates making, not to higher headquarters significant notification events, thereby focusing the staff and other collection efforts. CCIRs tailor the command and control organization of a unit and are essential for information management (USMC, 2001).

The Marine Corps planning process generates information requirements, which inform the process, or become assumptions for continued planning and result in CCIRs. During execution, beneficial CCIRs are linked to decision points for the commander (USMC, 2001). The two categories of CCIRs are: priority intelligence requirements derived from the information stream of the intelligence COP and friendly force information requirements derived from the operational and logistical COP. These requirements are necessary for the commander to assimilate holistically in order to make effective decisions.

Clearance and access levels create difficulties for source classification of data, but can be addressed using proven methodologies for protecting shared data objects. Data sources must incorporate data coloring into the information transmitted or stored. According to Hwang and Li (2010), data coloring is a viable technique for safeguarding multi-way authentications and controlling access for sensitive data. Within the private cloud architecture of the Department of Defense (DOD) data coloring can be applied to protect databases, images, video, software, and documents at varying security levels based on necessity. Only legitimate users have access to restricted data based on the level of security of the data storage combined with data coloring. Hwang and Li (2010) contend that the computational complexity of this type of encryption is much lower than conventional encryption and decryption techniques, such as PKI, inducing very low overhead to the DOD.

MAGTF commanders, geographically removed from the direct combat environment, observe the operation vicariously via three basic methods: battle rhythm, collection plan, and combat reporting feedback. All three methods provide critical information to the commander through distinctive interactions of the commander, the staff, higher, subordinate, and adjacent units. In the dynamic environment of warfare information overload is a potential threat mitigated by sound information management principles ensuring rapid, distributed, and unconstrained flow between units at every level. The policies and procedures emplaced by the commander’s information management practices enables the staff or IS to prevent information overload by discerning important, timely information from analyzed data in a focused manner directed toward a decision point.

B. COMMAND AND CONTROL

Information systems change the very nature of command and control (C2) (Alberts & Hayes, 2003). Information systems geographically displace the commander from the tactical edge of the battlespace. Clausewitz (1968) refutes the impact of information systems on the C2 process stating commanders work in mediums that are not visible. As warfare tactics and strategies have evolved with technological advances, the command and control node has been displaced further from the tactical edge (Van Creveld, 1985). Despite being geographically displaced from the front lines, the commander's necessity for objective, accurate, and timely battlefield information is paramount to attaining battlefield certainty (Griffin, 1991).

The Marine Corps' view of command and control, based upon doctrine that lags behind technological advances, expresses that doctrine is separate from a particular technology (USMC, 1996). C2 functionality is the fundamental requirement of any IS within the Marine Corps decision-making process for growth, survival, and success. C2 is not a specialized function within the Marine Corps, but instead the thread linking all functions and operations into the system to achieve an objective effectively measured in relation to the enemy. An effective C2 system will mitigate the effects of informational fog of war, and allow the decision-makers to rapidly orient themselves to the situation. Furthermore, as stated by Alberts and Hayes (2003), the C2 system will have the endurance to constantly monitor and evaluate the changing battlespace. Galster (2007) contends that future C2 will rely on sophisticated technologies for facilitating a complete situation awareness within the SOP. Effective C2 increases the commander's common operational picture and reveals decision points and appropriate actions that aid in achieving the commander's intent by utilizing standard operating procedures.

A dynamic view of Command and Control described by the USMC (1996) suggested that command is the exercise of authority and control is the feedback process relaying the effects of action back into the C2 infrastructure. Coakley (1992) described C2 as a process as well as the arrangement of the organizational structure, equipment, and procedures. Similarly, NDP-6 (1996) defined C2 as both a process "planning, directing, coordinating, and controlling of forces and operations" (p. 6) and system "personnel, equipment, communications, facilities, and procedures employed by the commander" (p. 6); in which the commander operates in both. Commanders decide what needs to be done and direct the conduct of subordinates while control is the continuous flow of current information back into the system allowing the commander to modify command action as necessary. Thus, C2 is an interactive process with mutually supporting systems to ensure the system adapts to environmental changes.

There are several important features to consider when considering C2 as a complex system of action and feedback loops (USMC, 1996). C2 is inherently an open system interacting with other systems freely, and must be sensitive to changes in the situation and adapt accordingly. Second, C2 is not a sequence of discrete events, but a continuous process as demonstrated by the action-feedback loop. The action-feedback loop also styles C2 as an interactive process requiring cooperation during dynamic environments to connect all elements together cohesively. The commander must also be an integral part of the system, not an outside influence to the C2 system. Lastly, C2 as modeled cannot provide precision, predictability, or autonomous order to the chaos of warfare. The human element cannot be entirely eliminated and should be redrawn from inclusion into the Human System Interface (HSI) workflows. Instead leverage the human's cognitive superiority over systems by driving the systems' workflow to generate meaningful knowledge. Additionally, this provides human validation of the systems' predictive and prescriptive alternatives.

Command and Control is made up of three basic elements: people, information, and the support structure (USMC, 1996). Concentration tends to focus on the information requirements and equipment interactions of commanders, but effective C2 involves qualified people applying a guiding philosophy in the use of appropriate systems. People collaborate with one another implicitly by using shared data structures for operational purposes to gather information, make decisions, and take action. This requirement creates the fertile ground to imbed Artificial Intelligence (AI) technologies into C2 as it adds to the automation of collaborative decision-making. The second element of C2 is information, which gives structure and shapes the surrounding beliefs, informing the decision-maker. Valuable information, often described in terms of uncertainty, timeliness, accuracy, and context, provides two distinct, but not mutually exclusive vantage points. These two vantage points are maintaining situation awareness and the directing of the executed course of action. Though distinct, maintaining situation awareness should be continuously occurring.

The support structure is the final element of C2, aiding in the creation, dissemination, and use of information. An important distinction is that the support structure is not solely equipment, but also the organizations, procedures, facilities, training, education, and doctrine. Ultimately, the goal of C2 is to maintain the situation awareness for the commander in order to implement decisions. These decisions are chosen based on the best course of action and direct the coordination of further actions. The execution and direction must occur while simultaneously coping with the fundamental challenge of uncertainty, timeliness, accuracy, and contextual relevance of information.

Coakley (1992) characterizes the information age by rapid, ongoing changes and incremental developments, particularly in the realm of technology. Coakley (1992) describes the technology of the information age as having produced spectacular increases in data available as well as the speed with which it can be delivered leading to overwhelming commanders. The technological improvements in individual mobility, communication range, weapon lethality, and information-gathering techniques compress time and space on the battlefield and increase the demand for *just in time* information. Rapidly developing situations necessitate continuously updated information to combat ineffectiveness of the C2 system. However, even with the realized advancements of information systems, it is important to dispel the notion that a specific technology can replace the human role in the decision support engine.

1. Derivations of Boyd's Observe-Orient-Decide-Act Loop

The fundamental theory for the command and control process begins with the basic observe-orient-decide-act (OODA) loop model, which describes the C2 sequence for a two-sided conflict. Figure 2 depicts Boyd's expanded sketch of the OODA loop as provided in the unpublished brief, *The Essence of Winning and Losing* (Boyd, 1996).

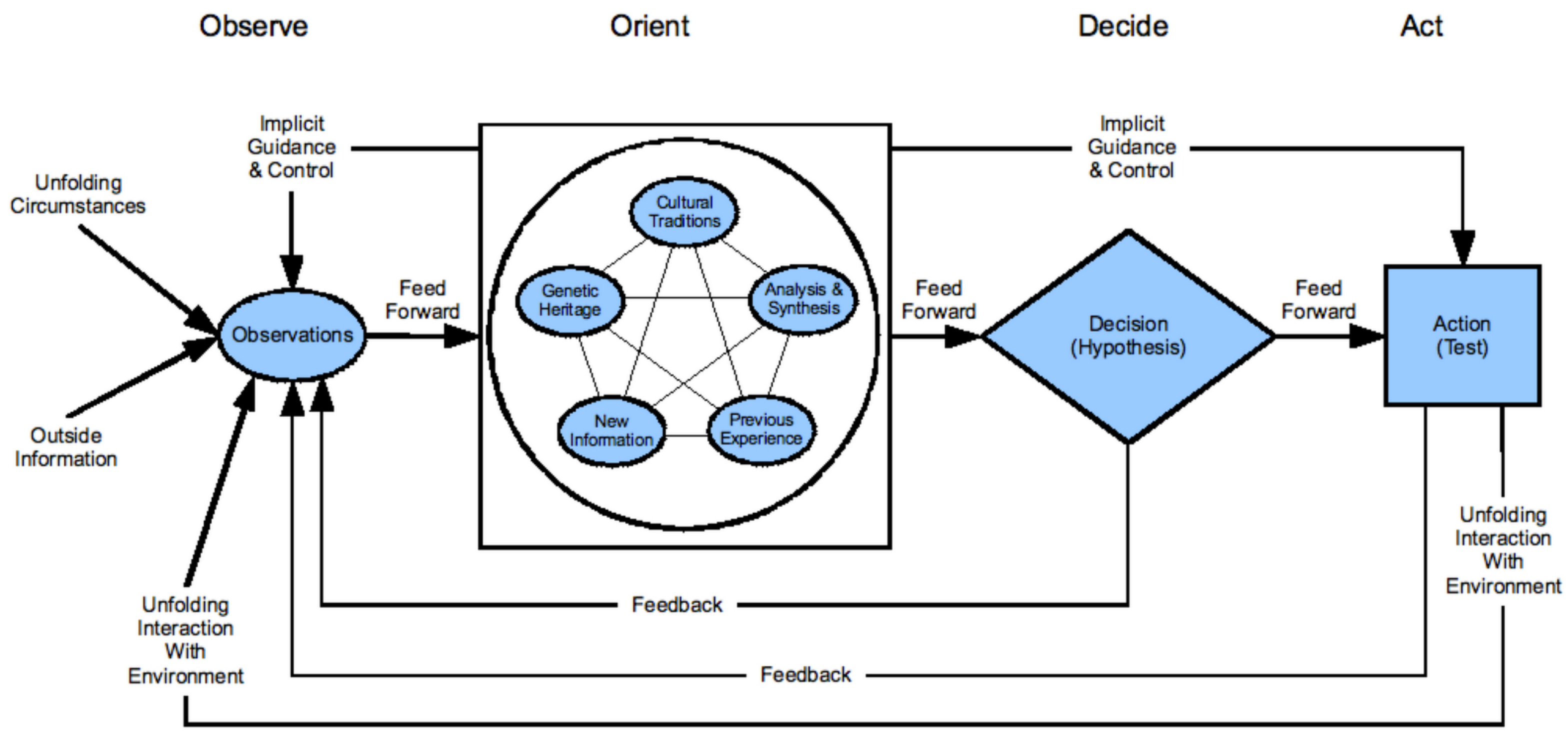

Figure 2. Boyd's OODA Loop (from Boyd, 1996)

The four phases of the OODA loop begin with observing the situation as it pertains to an individual's status, their enemies, and surroundings; and molding it into an understanding of the implicit guidance from higher. During the orientation phase, commanders create a coherent understanding of the situation utilizing estimations, assumptions, analysis, and cultural norms. This understanding is passed on to subordinates as guidance, from which subordinate commanders can base their decisions upon. Most importantly is the feedback process, which is continuously imposed from the decision and action phases as well as the changes within the environment as the enemy reacts of their own will. The prominent element of the OODA loop is creating tempo in the process, increasing decision-making speed relative to the enemy, and gaining the competitive advantage by forcing the enemy to continuously react to the situation. This theory is echoed in naval doctrine:

> Information fuels the command and control process…the naval commander must gather and use information better and faster than his adversary…A commander who makes and implements sound decisions faster than his adversary, increases the relative tempo of operations and leverages his capabilities in maneuver and firepower. (Naval Doctrinal Publication [NDP] 6, 1996, p. 4)

2. Data, Information, Knowledge, Understanding, Wisdom Hierarchy

The lowest classification in the data, information, knowledge, understanding, wisdom (DIKUW) hierarchy is data. According to Chen et al., (2014) data is the "uninterrupted raw quantities, characters, or symbols collected, stored, and transmitted" (p. 42). In the context of military use, data is the raw bits of unprocessed signals that have not been evaluated or interpreted.

The output of data into the information system is information (Batra, 2014, p. 6). Information is the next level of data classification according to the DIKUW model. Chen et al. (2014) state, "information is a collection of interpreted, structured, or organized data that's meaningful and useful for certain applications" (p. 42). As information is analyzed and integrated to gauge relevance, utilizing some form of cognition, the product is knowledge.

The next level of the DIKUW hierarchy is knowledge. According to Chen et al. (2014), “knowledge is acquaintance or familiarity about facts, truths, or principles gained through study or investigation” (p. 42). The foundation of statistical inference is that knowledge always increases with incremental information, but due to the concept of rare events, this theory is not true in all cases (Taleb, 2005). According to Lowenthal (2003), translating information to knowledge can be categorized as analysis; which is not limited to “sifting through accumulated data…but seeing the mass of material in its entirety and being able to perceive patterns from day-to-day anomalous reports” (p. 90). Deriving knowledge from anomalous reports is of great importance to the intelligence analyst; however, the operational commander values a predictive or prescriptive model to perform C2 (operations, logistics, METOC) analysis. The goal of any analytical information system is providing the *best* solution based on the veracity, quality, and timeliness of data.

Understanding follows knowledge in the DIKUW hierarchy. Understanding is the data cognitive process that is a result of synthesis or visualization, while gaining situation awareness. Understanding is the decision-maker’s application of their cognitive world model applied to the dynamic environment. This application attempts to identify and attempt to resolve areas of uncertainty.

The highest classification of the DIKUW hierarchy is wisdom. Though omnipotent certainty will never be achieved, information utility can be attained through limiting uncertainty (Taylor, 1965). According to Chen et al. (2014), “wisdom is sagacity, discernment, or insight to know what’s true or right for making correct judgments, decisions, and actions” (p. 42). Furthermore, Batra (2014) states “wisdom is cumulative knowledge tempered by experience” (p. 6). Therefore, in order for the progression of data to become wisdom, the decision-maker needs to utilize their understanding in an interaction with the dynamic environment. This interaction, or resultant experience, fosters wisdom.

Information is a generically used term to describe data at all levels in the DIKUW hierarchy. However, the value of the source data is in the utility that it provides as it is translated to organizational wisdom. Batra (2014) states, “Data itself becomes a key resource for an enterprise, and deliberate opportunities are created to generate data at innumerable data points to create value, thereby providing competitive advantage to an enterprise" (p. 1). Therefore, the utility of data in the command and control node is in the value that it adds to building an accurate SOP, which is the foundation for achieving a high quality of decisions.

The modern battlefield is a myriad of data collection sensors. As data is collected analysis needs to be conducted in order to filter and process relevant data to higher levels of the hierarchy. This type of analysis is what Lowenthal (2003) argues is the "wheat versus chaff problem" (p. 90) and minimizing the uncertainty in order to improve cognitive perception. Furthermore, Saracevic (1999) states that relevance can be defined as either cognitive or situational relevance. Cognitive relevance is the "relation between the current state of knowledge and cognitive information needs of a user" (Saracevic, 1999, p. 1059). The goal of cognitive relevance is to minimize the gap between the decision-maker's current situation awareness and the contextual representation of the dynamic environment in the digital world model. Situational relevance is "the relation between the information objects retrieved by the information systems and the situations the information objects are in" (Saracevic, 1999, p. 1059).

Information systems and technology are fully capable of gathering and processing raw data into information, however, in order to translate data into higher levels of the DIKUW framework, human interaction and experience is required. The cognition required to obtain knowledge is a human characteristic and transforming complex components of knowledge into situation awareness via intuition and judgment is a human trait based on experience. The transformation of raw data to higher levels of the DIKUW hierarchy is a product of the data integration, data fusion, and experience that occurs between each level of the hierarchy. Data integration is necessary to elevate data to information, while data fusion is driving the transformation of information to knowledge. The decision-maker's interaction with the knowledge base forms cognitive situation awareness. The building of this situation awareness occurs as knowledge translates into understanding. Utilizing this situation to base decisions results in actions, and the interaction of the decision-maker with the dynamic environment. The assessment of the decision-maker’s actions, and the resultant effects, translates understanding into wisdom.

Data integration reduces the data saturation of the decision-maker and enables rapid building of a SOP. Entirely removing the human interface is inconceivable for a C2 system, but creating an information system that can intelligently aggregate and summarize relevant authoritative (source, unaltered) data, will minimize the opportunity for decision-maker data saturation. Linking of relevant authoritative data to the decision-maker is paramount to securing the competitive advantage in the decision-making process.

3. Image Theory

Image theory is based on the premise that human beings do not think or understand best in terms of data or information, but rather images or mental pictures of a given situation, and assimilate information most effectively in terms of visual images. *Coup d’oeil*, literally meaning stroke of the eye, references “the ability of gifted commanders to grasp what is happening on the battlefield” (p. 72) via an image that symbolizes their understanding of the situation (USMC, 1996). Taylor (1965) contends that in order to escape the norms of bounded rationality, or omnipotent knowledge of all alternatives, a decision-maker constructs a simplified model, or image, of the real situation based on the data present (p. 60).

A second theory regarding decision making derived from observation and experimentation is observed decision behavior called naturalistic decision theory confronting the realizations that decision behavior seldom resembles normative processes (Beach, Mitchell, & Lee, 1998). According to Beach et al. (1998), image theory is a part of the evolution of descriptive theory from observations of real-life decision making based in cognitive psychology.

The decision-maker within image theory is an individual acting alone, not unlike the USMC command structure during operations, considering values, morals, and ethics that delineate perceived behavior and define the principles on which the commander establishes the foundations for decision making (Beach et al., 1998). Motivations of the decision-maker are driven by these principles combined with the achievement of a set of goals or objectives, which are achieved with a plan. Finally, when framing the decision, the cognitive effort is reduced based on the knowledge of policies, past events, and constraints emplaced within the context of the given situation.

The images described are important to commanders for their decision-making matrix. The first image is a close-up of the situation at hand, best gained through personal observation and experience. The second image is an overall view of the situation, which allows commanders to make sense of force disposition and patterns throughout the battlefield to gauge differences between the actual and desired situations. The third image is the attempt to view the evolving situation through the eyes of the enemy commander to anticipate enemy intentions. The first picture is very detailed, but narrow in scope. The second provides a broad vantage point, but less detail. Information systems ideally allow individual customization management of views derived from raw and aggregated images with easy navigation between each. The third image involves a mental exercise limited by the inability to truly guess the enemies actions. Adding enemy activity modules into the simulation matrices and running them against suggested COAs would provide feedback loops for the decision-maker.

Image theory recognizes two types of decisions, adoption and progress decisions, completed using either or both decision tests known as compatibility and profitability tests (Beach et al., 1998). Adoption decisions look at either adopting or rejecting candidate goals by eliminating unacceptable candidates based on incompatibility with the three images or selecting the best candidates from the screening based on the most attractive consequences defined in terms of the images. Progress decisions look at the plans and evaluate the compatibility between the forecasted future per plan implementation and the ideal future of the trajectory image. If they are incompatible then the plan is rejected in favor of a substitute. The compatibility test bases its evaluation on the compatibility between the candidate decision and the three images. The profitability test looks at the surviving candidates and selects the appropriate strategy as that which offers the greatest potential of being correct with the lowest estimated cost in terms of time, effort, and money.

4. Information Management Theory

"Getting the right information, to the right person, at the right time" (p. 96), is critical for command and control (USMC, 1996). The timely dissemination of appropriate information is the foundation for information management. There are two basic principles for communication initiation: supply (push) and demand (pull) (Kahan, Worlev, & Stasz, 2000). The principle of information supply is based on information from a source being pushed to the user on a schedule or as soon as it is obtained. This principle is advantageous for timely access without requests, but it requires anticipation of necessity and can quickly lead to information overload without some sort of filter. The demand principle of information theory lies dormant until a request for information (RFI) is made, and upon request, the demand disseminates down the chain of command until reaching the gathering source. Often this can lead to untimely fulfillment of the RFI or unnecessary degradation in the performance of the gathering entity.

The decision-maker with little to no situation awareness must rely on the IS to provide information. Future systems must be capable of aggregating data derived from multiple sensor sources and comparing acquired information to mission specifications. This aggregation capability could be done at higher, lateral and lower echelons to get combined with autonomous activity to provide the decision-maker with a product for requesting further information demands. The autonomous inputs in conjunction with higher, lateral, and lower echelon inputs build the baseline image for the decision-maker and increase his/her situation awareness.

One method that a commander can utilize to easily mitigate the inefficiency of information dissemination is by using Van Creveld's "directed telescope" (Van Creveld, 1985, p. 75). The "directed telescope" has been utilized throughout history as a way for the military commander to receive reports from outside the normal information reporting chain (Van Creveld, 1985, p. 75). Van Creveld (1985) explains that this means of reporting was necessary in order to avoid the "numerous stages through which they pass and the more standardized the form in which they are presented, the greater the danger that they will become so heavily profiled, (and possibly sugar-coated or merely distorted by the many summaries) as to become almost meaningless" (p. 75). This form of “information pull” is best suited to the military philosophy of decentralized command and the commander’s critical information requirements and is limited in usage as observers have distance (can’t see farther than a few miles) and vision (presence of darkness) constraints.

The way in which information is disseminated from one node to another is also important when considering information management. The broadcast method transmits information from a source to many (or all) users simultaneously, which is timely and efficient for generic information, but not ideal for specific commander’s requirements and again can lead to information overload rather quickly. In point-to-point transmissions, information is sent from the source node to specific user nodes, either all at once, or the information can be channeled through each node enroute to the final user. This method is slower and can lead to distortion of the data, but each node can act as a filter, integrating or analyzing information tailoring the outputs for the commander’s specific requirements.

5. Decision-Making Theory

Command and control procedures strive to enhance the decision-making ability of the commander. Uncertainty is inherent in military command and control decision making due to physics-based built-in errors in sensors reporting on the ground truth, and the enemy’s unpredictability. The Commander attempts to reduce uncertainty by gathering more information, but often the time required to gather this extra information is unacceptable for the given time constraints of the situation. The relevant elements of information getting to the decision-maker in the ideal amount of time are a better scenario than the inherent stagnation waiting for all of the information to be gathered.

Scholars provide two basic theories of human-based decision making as an analytical process and as an intuitive process (Klein, 1989; Kahneman, 2011). The analytical process involves the time-consuming review of machine-generated courses of action against a set of criteria to achieve the optimal solution via machine reasoning. Intuitive decision making, which is generally quicker, relies on a commander’s judgment based on experience, training, and reflection to derive the appropriate decisions to given situations based upon the significant elements of a given situation. Rather than gaining optimization in this type of situation, the commander elects to find a *satisficing* solution to the problem based on the idea that the conduct of war is an art vice a science (Simon, 1956). Typically intuitive decision making is associated with time-sensitive situations during combat when delays cause loss of life and analytical decision making is associated with deliberate actions such as contingency planning of supply ratios or capability requirements. Despite being conceptually distinct, these basic theories of decision making are rarely mutually exclusive (USMC, 1996). Information systems that place a human on the loop provide the decision-maker with enhanced machine thinking to achieve efficiencies in time and accuracy of decisions. Risk simulators that run COAs versus enemy action matrices drastically reduce the amount of time spent in the analytical process of human-based decision making.

6. Recognition-Primed Decision Model

Klein (1989) described the Recognition-Primed Decision Model (RPD) as a decision-making strategy that is adaptable to various situations. Depending on the decision-maker's "recognition and familiarity of the situation the decision-maker can react to cues and expectancies when visualizing and implementing their decision" (p. 58-59). This model is reliant upon the decision-maker's intuition, which is heavily dependent upon experience. Furthermore, Klein (1989) contends that "decision-making is the fusion of situation assessment and mental simulation" (as cited in Morris and Mitchell, 1995, 3845). Morris and Mitchell (1995) stated that "people use situation assessment to generate a plausible course of action and mental simulation to evaluate that course of action" (p. 3845).

The RPD is a model, which suggests that by providing the decision-maker with the facilities to increase situation awareness, the decision-maker will be able to make more efficient decisions. In order to achieve this higher state of situation awareness requires what Hanratty et al. (2009) stated is the "alignment of the decision maker's mental model with the intelligent software agents working on their behalf" (p. 1).

C. INTELLIGENCE

The theory of intelligence within the Marine Corps relies on the effective use of information, which has been processed into knowledge, about the enemy and the operational environment of the unit to support the decision-maker in the evaluation process to reduce, not eliminate, the uncertainty that permeates the battlefield (USMC, 1997b). According to MCDP 2 (1997b), intelligence is a central component of command and control corresponding with operations and logistics in preparation and planning to provide the opportunity for success in war. Sun-Tzu (6 century B.C./1991) stated "Know the enemy, know yourself; victory is not in danger; when you know sky and earth, victory is inexhaustible" (p. 87).

USMC intelligence assets strive to achieve these objectives: provide timely, accurate, and relevant knowledge about the enemy and environment and assist in protecting friendly forces via counterintelligence (USMC, 1997b). Images enhance understanding for decision-makers and intelligence analysts strive to process information into knowledge about the enemy and provide the commander with an accurate image of the current reality. Intelligence, like information, is perishable with time and too much information will overload the decision-maker. As a process, intelligence activities make up a significant portion of the observation, orientation, and action phases of the OODA loop.

The information revolution created an environment of easy access to the vast amounts of data and information collected on a regular basis, creating the danger of overload without properly emplaced filters and aggregators (USMC, 1997b). MCDP 2 (1997b) contends information systems are capable of graphically displaying data and information in a meaningful visual form, but still demonstrate difficulties generating knowledge and understanding, which requires human cognition and judgment.

1. Intelligence Characteristics

Quantifiably tangible factors provide the foundation to develop a better understanding of the enemy, but the intangible factors, which shape the enemy's actions during conflict, provide the greatest insight (USMC, 1997b). The intelligence process endeavors to understand the factors that shape the enemy's behavior in order to explain enemy activities thoroughly, thereby identifying enemy centers of gravity, critical vulnerabilities, and limitations to exploit (USMC, 1997b). MCDP 2 (1997b) states that certain characteristics of intelligence are exhibited as effective intelligence according to the Marine Corps' theory of intelligence.

USMC (1997b) intelligence activities focus on seven characteristics including: objectivity, thoroughness, accuracy, timeliness, usability, relevancy, and availability. Intelligence must be objective, free from bias and distortion of human interpretation and manipulation to conform to preconceived notions or support prior conclusions. Characteristics such as timeliness, usability, and availability, are mutually supportable. These characteristics approximate that information must be provided to the decision-maker in a clear and concise format that enables timely action. According to MCDP 2 (1997b), information that is thorough and accurate, which means sufficient in depth to satisfy requirements and factually correct, are at odds with timeliness because intelligence is perishable with time. Lastly, intelligence must be relevant; meaning pertinent to the level of command intended and significantly bear upon the situation in question (USMC, 1997b).

2. Intelligence Classes

According to MCDP 2 (1997b), two classes of intelligence are included in theory: descriptive intelligence, which describes past and current conditions, and estimative intelligence, which attempts to predict future conditions. Descriptive intelligence has a basic component, which is general background knowledge describing open source characteristics of hostile nations and their military forces, and a current component, which are more changeable factors, traditionally more specific than basic intelligence but less reliable and harder to obtain (USMC, 1997b). Estimative intelligence focuses on potential developments, attempting to evaluate previously gathered information to anticipate enemy actions and anticipate possible future movements or scenarios (USMC, 1997b). MCDP 2 (1997b) asserts that the two classes of intelligence are distinct, descriptive focusing on capabilities and estimative distinguishing intentions, but inseparable in a decision-maker's consideration of all pertinent data. Any effective intelligence picture must provide insight into both (USMC, 1997b).

3. Intelligence Collection

The collection of intelligence begins the flow of data into the decision-making cycle. The modern battlespace has an abundance of sensors that relay unfiltered data to the decision-maker. According to Builder, Bankes, and Nordin (1999), the modern decision-maker is faced with the problem of having "too much information, rather than too little" (p. 1). Though technology has evolved giving the modern warfighter many tools, the command and control process has lagged behind in being able to efficiently and effectively implement these tools. The modern decision-maker needs to have the ability to rapidly interpret the abundance of data presented in order for the data to be transformed into relevant information to base a decision upon.

In order to more accurately interpret presented data, the decision-maker must have an understanding of the method of how the data was collected. According to Waltz (1998), the utility of the data collected "is a function of both the accuracy and timeliness of information delivered to the user" (p. 72). Information must be derived from an authenticated sensor and stream of data. If the decision-maker has to question the authenticity of the data stream, the utility of data and competitive advantage is lessened, if not lost.

Research by Lim, Moon, and Bertino (2010) addressed the importance of the trustworthiness of collected data. According to Lim et al. (2010), the utility of vast sensor networks will be dependent upon the "assessment of the trustworthiness of the collected data and indicating to the decision-maker the trustworthiness of the data" (p. 2). Lim et al. (2010) suggested attaching a *trust score* to collected data. The assessment of the trustworthiness of the data relative to other sensors can aid the decision-maker during their decision-making process. This method will allow the decision-maker to focus, and base their decision upon data with higher trust scores.

Bertino, Dai, Lim, and Lin (2008) suggested that the "core requirements for data integrity control systems are based upon information-flow control, data verification, prevention of fraud and errors, and autonomous data integrity validation” (p. 247). Similarly, Waltz (1998) stated, “information utility is a function of both reliability for and availability to the user” (p. 73). In summary, the utility of the data acquired is limited by its trustworthiness, authenticity, and reliability.

4. Semiotics and Visualization

The translation of data to higher levels of the DIKUW framework can be accomplished through the use of semiotics. The use of semiotics has been useful. According to Vickers, Faith, and Rossiter (2013), “semiotics is the study of the creation and interpretation of signs” (p. 1049). Signs, or raw data collected from sensors, sit at the lowest level of the DIKUW hierarchy. Without interpretation of this data, it will not matriculate to higher levels on the DIKUW hierarchy. According to Vickers et al., (2013), “data is purposefully collected from the real world and, via mappings, representations are produced. These are used in turn for meaning making and drawing inferences about the data. The visualization process encompasses cognition in the observer’s mind” (p. 1050). Therefore, through the visualization of complex data; higher levels of the DIKUW hierarchy can be achieved quicker.

The dynamic environment in which the decision-maker must build a SOP is constantly changing. Meystel (2003) states that semiotics offers the decision-maker the ability to conceptualize the dynamic environment:

> By constructing signs and systems of signs, by creating and maintaining laws of symbols formation and interpretation, by arranging them into a multi-resolution (multi-scale) system, by discovering rules of transformation between levels of resolution and between the symbolic system and the reality (re: symbol grounding), semiotics works as a tool of constructing the system of world representation, its interpretation and meaning extraction. As soon as this representation is ready, semiotics-teaches us how to make decisions upon this representation, create plans and generate activities. (p. 419)

Building a SOP of a dynamic environment will not yield situation awareness with complete certainty, but visualizations that match a human’s cognitive environment model closer will help the decision-maker understand and orient themselves more efficiently.

According to Zheng, Wang, Luo, Cao, and Qing (2011), assisted by visualizations, “large amounts of information can be displayed in a visual specific way…that will promote a deeper understanding to the decision-maker which will help them to observe and analyze…and improve the ability of decision-making performance” (p. 781).

D. LOGISTICS

The USMC (1997c) theory of logistics acknowledged the importance to warfighting and established operational possibility including a definition of logistics as the provision of combat power, flow of materiel into the area of operations, and the sustainment of resources throughout operations. The most important decision for the Commander with regard to logistics is how to effectively use the limited resources available to accomplish the ultimate mission. There exists a dynamic relationship between logistics and operations, but ultimately logistics sets the outer limit on possibilities for operational feasibility throughout all levels of warfare (USMC, 1997c). Advancements in information systems have significant effects upon logistics functions including better information processing and communication that improve resource management and open information networks allowing easier exchange of data, information, and processes.

The MAGTF Commander’s focus on tactical logistics sustains the force in combat, which involves the actual performance of the logistics functions with an understanding of the enabling support of the operational level of logistics and the foundation of strategic logistics utilities (USMC, 1997c). It is crucial that the decision-maker’s information system’s logistics function reaches higher, lower, and laterally in order to best support ongoing operations. Commander’s need to ascertain the common logistics picture by analyzing available data pulled from the common logistics database and displayed on their personal devices.

1. Science of Logistics

Logistics is the most concrete factor that determines the outcome in warfare based on facts, relationships, and rules that form the basis for calculation and prediction (USMC, 1997c). MCDP 4 (1997c) provides standard planning factors and formulas are available to predict the necessities for movement and sustainment of forces to overcome the passive obstacles: time, terrain, and distance. Due to these available calculations and passive obstacles, the ratio of inputs to outputs is more predictable for the logistics function of war than operations or intelligence (USMC, 1997c). Analytical tools, vice simple templates, are still required for proper planning for any situation, in order to adjust to changes in assumptions. The data required for analysis is typically of a structured nature and easily assimilated into online analytical processing tools (OLAP) available to the decision-maker.

2. Logistics System

The Marine Corps (1997c) acknowledged a system of logistics based upon "a distribution system composed of bases and procedures" (p. 45) and the established command and control system. Without arguing the importance of the ideal operating and staging base layout of an inherently expeditionary force like the Marine Corps, whether ashore or afloat, and the push-pull procedures needed to ensure fulfillment of required resources, no logistics system is effective without the implementation of adequate command and control (USMC, 1997c). Linking the distribution system to the planning and execution of operations is the design foundation for a logistics information system application. Information technology accomplishes three tasks for the Commander while balancing effectiveness with efficiency: anticipating future requirements, properly allocating resources based on prioritization, and dealing with the uncertainty inherent in combat (USMC, 1997c). As is common with commercial sector logistics functions, military logistics entities are moving toward a *just-in-time* concept of logistics in order to improve the efficiency to effectiveness ratio.

IT logistics systems are increasingly being implemented into the execution of military logistics functions as a force multiplier enhancing planning and execution. These systems are generally used "to process support requests, track resources, store consumption rates and usage data, estimate future requirements, and develop schedules for orders and deliveries" (USMC, 1997c, p. 113). Additionally, logistics information systems exchange resource data and distribute real-time allocation, laydown, and resource movement information throughout applicable commands. These tools are automated for use by logistics technicians, but decision-makers need improved IS for analytical purposes in their planning and execution tasks for operations.

Integrating logistics factors into the operational planning and decision-making templates is now possible with logistics IS. Near real time information located in the data warehouses is accessible through the IT architecture. Current systems are capable of conducting analytics regarding estimated capabilities, trends and resource tracking to incorporate into planning and execution decisions. Although disconnected applications are capable of these techniques, the ideal technology places the commander on-the-loop of information workflow-driven exchange between logistics and operational planning and execution allowing each decision-maker to customize integration of supply and demand workflows.

E. PROVENANCE, LINEAGE, AND PEDIGREE

Pedigree, commonly referred to as provenance and lineage, is the "quality of data" that is being utilized in a database (Glavic & Dittrich, 2007, p. 227). According to Glavic and Dittrich (2007), data warehouses are comprised of data integrated across many sources. Often, the quality and source of this data comes into question when the decision-maker utilizes this data to construct a representative model of the environment. Due to the various sources of data, and multiple users utilizing the data across many databases, the original source data is regarded with higher utility. This data can be thought of as *authoritative data*, which is the original, unaltered, source data. The authoritative data is often copied, or represented, in other databases in the data warehouse.

When utilizing the data to form an accurate picture, the decision-maker needs to utilize the authoritative data, vice data that has already been manipulated. By applying a pedigree rating to the authoritative data, analytics can be performed on "organizational workflows" to identify underlying patterns (Glavic & Dittrich, 2007, p. 228). Furthermore, according to Glavic and Dittrich (2007) the use of authoritative data lends itself to “interactive statistical environments, visualization and knowledge discovery in databases (KDD)” (p. 228).

As complex organizations look to integrate across multiple data streams, the value in the end architecture lies within the utilization of the authoritative data. During the analysis portion, greater interpretation of provenance and pedigree will be applied to knowledge visualizations and the implementation into DSS. Provenance, lineage, and pedigree possess additive implications toward the quality of the data utilized within the DSS.

F. SUMMARY

Decision-making theories such as Boyd’s OODA Loop, the DIKUW Hierarchy, Image theory, Information Management Theory, and Decision Making Theory suggest that the timely processing of relevant data to information is integral to maintaining highly accurate situation awareness from which to base decisions. The use of Decision Support Systems (DSS) such as graphical user interfaces and visualizations can more efficiently and rapidly aid the commander in achieving a higher degree of situation awareness of the battlefield or his own forces.

The use of a graphical user interface or visualizations as a DSS allows the commander to gain rapid situation awareness; however, this representation is only as accurate as the data supplied to the DSS from the data warehouse. Accurate source data will enable a highly accurate representation to be pushed to the commander. From this picture the commander will have a higher degree of certainty from which to base their decision. The rapid transformation of uncorrelated data to relevant information will enable a more efficient and accurate foundation to base a decision. The rapid orientation to the situation, and attaining the necessary level of situation awareness to base a decision upon, will enhance operational agility.

The United States Marine Corps has embodied a decentralized command structure. Currently, United States Marine Corps commanders have to pull information from command and control systems and subordinates; rather, than having information pushed to respective command tiers. In order to maximize the agile benefits that a decentralized command structure offers, USMC doctrine and command and control infrastructure needs to be modernized to reflect the technological enhancements that corporations such as Amazon, UPS, and FedEx have embraced in utilizing graphical user interfaces and visualizations to achieve higher states of situation awareness for the decision-maker.

III. DECISION-MAKERS' CRITICAL INFORMATION

According to the Deployable Training Division (DTD) J7 (2013), Commander's Critical Information Requirements (CCIRs) are acute components of information identified by the commander for facilitating timely decision making and are developed to support two major activities: understanding in an increasingly complex environment and decision making. These two activities are achieved by linking information requirements to execution of future options within the operational plan. The research focus is at the MAGTF Commander level of campaign analysis, but the models are capable of employment throughout the continuum of command.

CCIRs doctrinally contain two elements: priority intelligence requirements (PIRs) and friendly force information requirements (FFIRs) (DTD, 2013). Throughout execution, continuous mission assessment is conducted and depicted within the digital world model (DWM) as a shared operational picture (SOP). By leveraging the decision support system (DSS), the SOP promotes shared situation awareness via rolling-up to the upper command level or drilling-down to the lower command level to obtain a holistic knowledge. Based on shared situation awareness, CCIRs direct the collection plan, analysis, and dissemination of information to support decision-makers in setting ideal conditions for operations. Ultimately the decision-maker with the most inclusive holistic view of the mission, based on the SOP, dictates PIRs. CCIRs belong exclusively to a particular commander within an area of operation (AO) and are a product of mission analysis, updated throughout the evolution of an operation (Joint Staff, 2011).

PIRs focus on the enemy and the environment for operations, while FFIRs focus on friendly forces and supporting capabilities (Joint Staff, 2011). Within the scope of the information hierarchy depicted in Figure 3, PIRs and FFIRs reside in the realm of knowledge, derived from the analysis conducted on essential elements of information (EEI) and essential elements of friendly information (EEFI). EEI and EEFI are data streams that require analysis in order to provide proper scope to the information reported to the commander. Algorithmic models biased with user inputs in conjunction with the decision-maker's staff, which possess an understanding of the mission and unit roles, are utilized to create higher levels of information from the raw data streams to produce the PIRs and FFIRs, which the commander has approved as CCIRs. The commander conducts personnel cognitive reasoning on these CCIRs and with the addition of experience, reduces uncertainty in understanding the operational situation to generate decisions focused on beneficial outcomes.

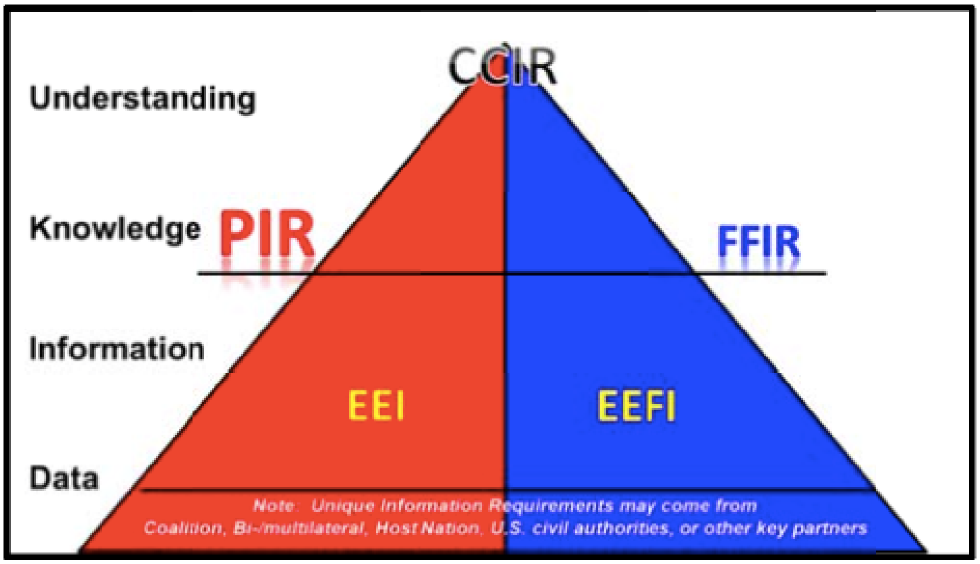

Figure 3. CCIR and Information Hierarchy Integration Model (from DTD, 2013)

Operational commanders at the MAGTF level must broaden their CCIRs to support time-sensitive execution as well as long-term mission planning (DTD, 2013). The selected CCIRs must provide knowledge, vice simply data and information. Additional attributes of broader CCIRs include collection prioritization and focused analysis with detailed understanding of the higher and lower echelon desired end states through shared data model to achieve a SOP. An automatic or semi-automatic aggregation (via summarization) of operationally relevant prioritized data sets will alleviate bandwidth saturation for the commander's network and reduce the commander's workload. Increasing decentralization of the decision matrix to the appropriate level of command delegates the CCIRs retention requirements from higher headquarters units to lower units, thereby relieving stress on collection and analysis resources.

CCIRs span the future and current event horizon for operations (DTD, 2013). Future operations and planning focus on the *what's next* and the *what if* branch and sequel plans required of operational units based on the assessment of available enemy and friendly information, including joint and coalition partners. Current operations focus on task accomplishment and execution.

The information needs of the commander are neither finite nor applicable across all operational scenarios (Kahan, Worley, & Stasz, 2000). The complexity of the operational environment exponentially increases the potential options that operations may take. Unlike tactical level commanders whose CCIRs may contain specifically worded PIRs and FFIRs, operational level commanders derive decisions based on a broader assessment of the measures of effectiveness (MOEs) and further analysis of the overall strategic or operational objectives (DTD, 2013).

Kahan, Worley, and Stasz (2000) also emphasize that information necessary for the decision-maker is not simply data streams from one unit or another, but instead fused data from the DWM by linking the DSS to the knowledge base maintained by the DWM. Enemy intentions are estimates only due to individual free will; therefore predictions are based on strategic objectives, political climate, and economic conditions supported by intelligence analysis. Critical information mitigates a portion of uncertainty in decision making, but cannot relieve all uncertainty. Ideally the commander keeps CCIRs narrow in scope, but fluid enough to correspond to changing scenarios. To manage this difficult balance the IS may impose a requirement on the DWM to generate a CCIR library of templates for the decision-maker's semantic search and data entry.

A. INTELLIGENCE

Intelligence requirements focused on the enemy force and operational environment doctrinally are established as PIRs. An intelligence requirement is an unknown piece of information about the enemy or environment, a question about the threat or the battle space, necessary for the decision-maker to act (USMC, 2003). During mission analysis, the Joint Staff (2013a) identifies significant information gaps about the enemy and operational environment that require further collection of information or intelligence production. The commander has overall approval authority of all CCIRs, to include PIRs, but relies on staff recommendations for priority level distribution. PIRs are developed for each phase of an operation and are updated throughout the execution of operations based on the flexible nature of warfare.

Most PIRs are in reference to the adversary's intended Course Of Action (COA), most dangerous COA, and enemy critical vulnerabilities (USMC, 2003). The intended COA is prioritized at the highest level due to its relative likeliness of occurring as opposed to the most dangerous, but less likely to occur, COA. The critical vulnerabilities of the enemy are equally as important as the adversary's intended COA and necessary to understand for the implementation of maneuver warfare doctrine. Analysis of this type requires the collection of data and available information as well as experience and judgment. Fundamental to the task of the analyst in obtaining the PIRs for the decision-maker is helping the commander visualize the possible threats within the AO (Haigler, 2012). Enemy force laydown, movement, location, size, capability, and readiness are critical elements of information necessary to the decision-maker, particularly in reference to the enemy centers of gravity. Additionally, high-value target (HVT) and high-value individual (HVI) location and disposition are established criteria for the decision-maker in the current operational environment. A thorough list of PIRs suitable for any operating environment is depicted in Table 1. These intelligence information requirements are ideal for a decision-maker in any AO to begin planning and conducting operations.

Priority Intelligence Requirements for the Decision-Maker
1. Severe weather forecast or change affecting current or planned operations, air, land, or sea.
2. Graphic overlay for historical enemy attacks by category based on commander input and selected timeline.
3. Estimates on Enemy intentions, predicated based upon enemy's assumed strategic objectives and predictive analytics based on historic attacks and enemy movement.
4. Enemy force laydown (location), size, capability, and readiness.
5. Relevant enemy unit movements: expected and unexpected.
6. Relevant changes in enemy protective posture. (IADS, Watch rotations, etc.)
7. Indicator of local populace feeling toward coalition operations within their sphere of influence.
8. HVT/HVI location and movement.
9. Gain or Loss of a human intelligence asset, circumstances, and their Area of Influence.
10. New analysis report for selected AO or HVI/HVT.
11. Human Intelligence analysis reports for reference. (text-rich documents searchable by multiple criteria)
12. Video surveillance stream in reference to HVT/HVI.
13. Video surveillance stream in reference to current operations and strikes.

Table 1. Priority Intelligence Requirements (after Joint Staff, 2013a; Kahan, 2000; USMC, 1997b; USMC, 2003; USMC, 2004)

Haigler (2012) contends that sources of information for evaluation are obtained from a variety of resources. The techniques for acquiring such information as force laydown, location, and movement of enemy forces and HVTs ranges from Human Intelligence (HUMINT) and Signals Intelligence (SIGINT) sources to the use of Imagery Intelligence (IMINT) sources such as unmanned aerial vehicles (UAV) and satellites. The size, capability, and readiness rates of an enemy force is derived from HUMINT as well as Open-source Intelligence (OSINT) sources typically assimilated prior to conflict. Assumptions in pre-operation activities are bolstered with HUMINT details to increase accuracy. Bottom line is analysts must acquire information from all available sources to reduce biases in judgment or cause blindness to a threat (Haigler, 2012).

EEIs referencing the physical operational environment gathered via IMINT, SIGINT, OSINT, and other sources represent the "ground truth" of the Physical World

Model (PWM). The PWM, via information extraction, is seamlessly integrated with the DWM as the visual depictions. The advancement of this fusion concept is an ongoing IT capability advancement. Social aspects of the operational environment, which are derived from HUMINT sources, are not so easily created, often requiring deeper analytical evaluation by intelligence professionals and reported up the chain-of-command with levels of hypothesis. These resources derive knowledge based on time sensitive information irrelevant after an unspecified period. Typical documentation is text-rich data, time consuming to search and difficult to portray via graphical visual format, instead requiring textual based IS for depiction. Commanders must rely heavily on intelligence resources and analysts to provide appropriate information to fulfill PIRs. However, access to the basic EEIs must be available for the commander to view and support the conclusions of the analyst.

Fulfilled PIRs exist to inform the commander of critical information, and also to help a decision-maker understand a prioritization of the type and level of intelligence resources required to support the operation (Joint Staff, 2013a). Continuous campaign assessment by higher headquarters along with prioritized PIRs justifies the tasking of national intelligence gathering resources and further intelligence capabilities. The probability of gaining access to national assets as resources is greatest when PIRs are in coordination with national priorities, and much less when the fulfillment of a PIR would require recuing of national resources. Answered PIRs lower the level of risk for a given operation, but are time relevant. When making information requests, they must be accompanied by the latest time for the intelligence to be of value to the Commander.

Time constraints increase stress on national assets and decrease the probability of access to these resources. There is a dichotomy to timeliness of information. The usefulness of information is based on timeliness, and is most important to the operator. If the right information does not make it to the operator at the right time, more risk is incurred for the operation. Recuing information-gathering resources is also temporal. Different assets have different timelines and procedures for recuing based on the complexity of the systems. These two timelines are often at odds with one another and cause stress in the request process. Prioritization of information requirements provides a mechanism for the commander and supporting unit to communicate necessity. Commander's expect unsatisfied information requests due to the conflict of information timeliness at the expense of resource recuing, but continual request and operational necessity will, in a relatively (in operational terms) near future, force the requested resource recuing. It is understood this may happen at the expense of denying competing information requests with lower priorities. Essentially, this is a resource allocation problem requiring optimization. Management of intelligence requirements is essential for successful planning and implementation as well as ensuring no duplication of effort. As depicted in Figure 4, there are many contributors to the master intelligence requirements list, but only the decision-maker determines each priority, and the staff must confirm what requirements are actively being pursued and which are not.

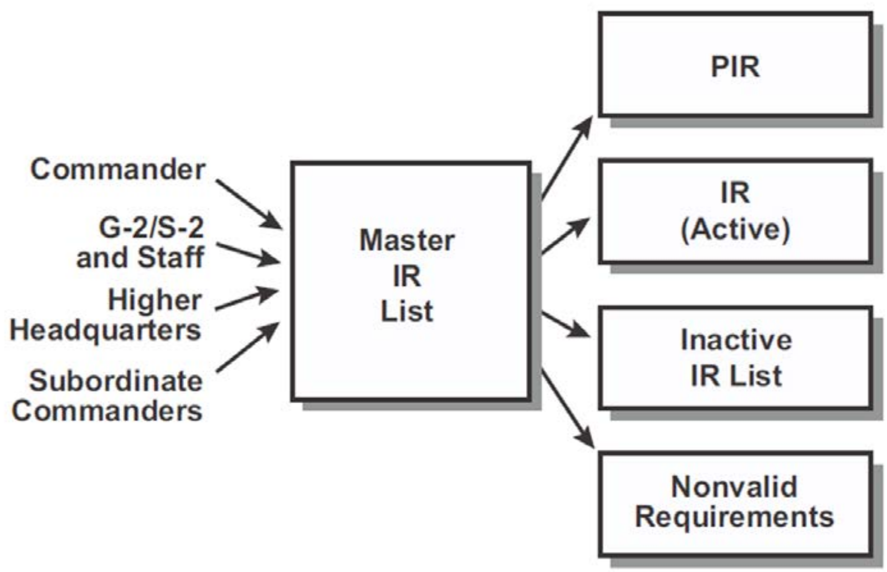

Figure 4. Intelligence Requirements Management (from USMC, 2003)

Continual assessment of the mission execution is essential to properly align intelligence operations and optimally allocate sensors to achieve campaign objectives. Additionally, maintaining open communication with outside agencies ensures updates regarding non-organic intelligence requirement achievement.

B. OPERATIONS

CCIRs related to operations are firmly established in doctrine as FFIRs (DTD, 2013). These information requirements are linked to friendly force laydown, movement, location, size, capability, readiness, and personnel status (USMC, 2010). A MAGTF Commander needs to know where his forces are physically located within AO in order to reduce conflict of force movement and fires, redundancy of effort, and increase force protection against discovered enemy movements (USMC, 2001). The size of the unit is important for reference purposes to verify number of personnel within an AO. The capability of a unit is referenced not only to what they are trained to accomplish, but also what the unit is currently supplied to accomplish, whether that is in reference to ammunition and food, or number of helicopters and personnel carriers available for movement to an objective.

A unit's readiness is always a fluctuating factor that a commander needs to maintain knowledge of prior to placing a unit into action. Due to the fluctuation rates of such a variable it is important to maintain the most up to date information regarding such items as readiness. Readiness is exemplified in several formats including training, personnel, and materiel (USMC, 2001). A deployed unit should attain and maintain training levels at the appropriate threshold prior to and during deployments, but rates fluctuate within the continental United States (CONUS). The status of personnel and materiel readiness consistently oscillate due to sickness, injury, death, material degradation, and cyclical inspections. The minutia of unit readiness is far too much information for a MAGTF Commander to maintain at all times, but is important to have access too when relevant for a decision.

Ideally a commander maintains a 'God's-Eye' view of operational forces updated continuously via a database record populated by legacy information systems such as blue force tracker; a GPS based location database that auto-updates at prescribed intervals. Operational laydown and movement is the most important critical information requirement for a commander's operational control and continuous situation awareness (USMC, 1996). Every unit commander should be permitted access to the 'God's-Eye' view of operational force laydown and movement within the SOP architecture.

Specificity down to the most basic combat unit, the four-Marine fire team, is expected as a system requirement. This requirement could easily create clutter for the displayed output and is not always necessary for the commander’s situation awareness. The level of clarity is ideally based on the level of resolution and entity aggregation levels the commander has been choosing interactively on the moving map application and other applications, not requiring a map, necessary for predictive and operational planning. The DSS must possess optional capabilities that are customizable (aka configurable) by the user for the aggregation attributes to display the views to avoid the clutter of the display and cognitive capability of the decision-maker. Table 2 lists the ideal operational information requirements for a decision-maker to plan and conduct operations within any AO.

Operations Information Requirements for the Decision-Maker
1. Friendly force laydown (location), size, capability, and readiness.
2. Readiness indication of every unit within the overall command.
3. Relevant unit movements: expected and unexpected.
4. Notification of completion for each significant Operational Checklist event.
5. Joint force or Coalition Force movement within AO.
6. Status of NGO and other aid operations within the AO.
7. Any transitory unit within the AO: intended routing and actual progression.
8. Video surveillance stream in reference to current combat operation.
9. Video surveillance stream in reference to current air-to-ground strike.
10. Loss of a unit commander within the command structure.
11. Details regarding captured Marine or shot down aircraft and first estimate on TRAP (tactical recovery of aircraft and personnel) mission status.
12. Loss of a key communications node, facility, or retransmission site.
13. Communication loss to any unit within the overall command or AO.

Table 2. Operations Information Requirements (after Joint Staff, 2011; Kahan, 2000; USMC, 1996; USMC, 2001; USMC, 2010)

The Marine Corps doctrinally incorporates centralized command with decentralized control allowing the sub-commanders to make the important tactical decisions in reference to their understood commander’s intent and operational objectives (USMC, 1996). It is important for the sub-commanders to make necessary decisions based on available information toward achieving the common objectives, but without pushing constant updates back to the commander’s staff. Autonomous information systems provide the commander with a continuously updated SOP. The SOP enhances the situation awareness (SA) of the decision-maker allowing the Commander to provide course corrections to subordinates as necessary or preserve continuous action without mandatory reporting breaks maintaining tempo in operations (USMC, 2014b). Course corrections are only relevant in operational situations conducted in conditions of little uncertainty and low friction. DSS cannot subjugate USMC doctrine of decentralized control and therefore in conditions of uncertainty, fog of war, Commander’s must maintain a balance between relying on the judgment of subordinate decision-makers on scene assumed to have the greatest SA of the current engagement first and Commander’s experience next.

The sub-systems, such as blue force tracker also provide movement and location data to the superior commander at near-real time. This force laydown information allows the commander to track progress as compared to timelines and maintain situational awareness to the progress of ongoing operations. This type of information provides the commander necessary cognition of operational progress in order to determine placement of the reserve or redirection of limited fire support assets. This near-real time location information provides all commanders with progress in order to maintain situational awareness to the operational checklist progress as well, saving valuable time in unnecessary communication between subordinate and senior units regarding status updates.

The secondary critical information requirements that a MAGTF Commander must maintain involve their forces’ readiness rates. Subordinate commanders incorporate this type of information into the shared data space via inputs, which enhances the SOP effectiveness. The information change provokes a status update or notification for the

MAGTF Commander's system when specific criteria are met. Readiness rates are ideally relayed post engagement or operation, but are dependent on criteria provided by the MAGTF Commander. If specific criteria (rules) are reached, the subordinate commander is expecting the IS to generate an automatic trigger, enabling a "push to update" the superior commander based on standard benchmarks. Every commander provides inputs and corrections to the SOP to ease collaboration efforts between different echelons.

Unit capability is also a secondary information requirement that is only important to the MAGTF Commander when it degrades from expected levels. This type of degradation could occur due to readiness degradation or materiel failure out of the positive control of the unit commander who experiences the capability degradation. These factors outside of the control of the unit commander may be unknown, however, the MAGTF Commander will still have access to the information, due to secondary reporting criteria from other unit's readiness rates, such as a logistics unit. Utilizing the OLAP cube data model to manage the metadata for the SOP enhances propagation of newly reported and updated metadata throughout the chain of command and laterally through the operational force. The importance of linking one units readiness to another's is essential to have correctly set up within the IS intelligence analysis and ideally would notify the superior commander when specific thresholds were reached.

It is essential for the MAGTF Commander to maintain situational awareness to the ongoing friendly force laydown and up-to-date movement and locations in order to progress toward operational objectives and achieving Commander's Intent. A graphical representation of friendly force locations provides the ideal picture for a superior commander to maintain such awareness. Unit name depictions, manpower readiness, and days of supply are important inclusions in the visualization mechanism and should be defaulted into the visualization environment of the DSS. Other readiness information is best suited as optional information for the visualization environment based on drill down, clutter, and customized to the individual cognitive ability of the decision-makers. Kahan et al. (2000) profess the dangers of overloading the commander with information, and the disastrous ramifications that ensue. The threat of information overload and display clutter mandate display systems provide secondary information in a visual notification format, such as a symbol color change or flicker, which could be hidden if the decision-maker desires. This allows the commander to better draw attention to the unit that needs the commander's attention due to a better recognition of a specific situation that is dictated by thresholds configured into the information system.

C. LOGISTICS

Friendly force logistics and supply data is qualitative in nature and lends well to business intelligence methods for analysis and decision-making. Doctrinally, logistics and supply information is categorized as FFIR, but certain information is essential for the enemy's situational awareness and could be adapted as EEFI (Joint Staff, 2013b). EEFI are no longer doctrinally incorporated into CCIR, but the Joint Staff (2013b) advises safeguarding EEFI from enemy detection or operations run the risk of compromise and failure.

Logistics information and functions relevant to the MAGTF Commander spans all three levels of war from Strategic to Tactical requiring feedback from lower echelon units using continuous push updates of information from national and regional level entities. Current software capabilities infused into logistics decision support generate event notifications when changes or updates are entered into the database. Event updates are pushed to users within the SOP shared data model architecture. These events update trigger action sequences within the workflow for a functional area affected. Figure 5 depicts the support and requirements flow of logistical functions within the MAGTF. Every level provides important information necessary for the conduct of operations for the MAGTF.

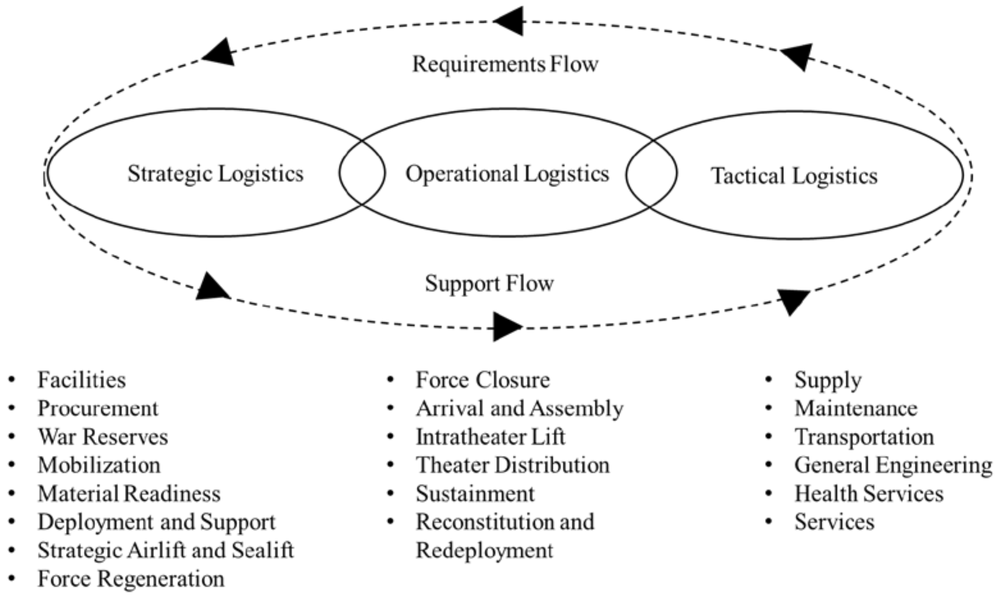

Figure 5. Logistics Information and Function Flow (from USMC, 2002)

The logistics continuum, demonstrated in Figure 5, spans all three levels and each level has a corresponding set of functions. The MAGTF Commander focuses heavily on the Operational and Tactical level of the continuum. Operational logistics support major theater operations and coordinate closely with tactical logisticians to ensure the combat units possess the necessary resources.

The interface of these data streams is often in different languages leading to difficulty integrating individual databases into one data warehouse. Essentially, the logistics C2 system would be the singular provider for decision-maker visibility into deployment surge and sustainment logistics, for all service components, mobility commands, contract organizations, and defense logistics agencies (Schrady, 1998). A baseline for logistics information requirements for the decision-maker within any AO is depicted in Table 3. These information requirements are the stepping off point for any planning and operational conduct regarding logistics for MAGTF Commander.

Logistics Information Requirements for the Decision-Maker
1. Sustainment Stock Levels.
2. Alert at reaching below 75% of sustainment stock.
3. Consumption rates of each consumable category, referenced by the commander’s prerogatives.
4. Graphical trends in consumption rates: Planned versus Actual.
5. Severe weather forecast or change affecting current or planned logistics movements by land, air, or sea.
6. Theater lift capacity measured in reference to how many units can be moved at present and any requested future timeframe.
7. Any time logistics support for the designated Main Effort degrades.
8. Indications, warnings, or actual attacks on critical logistics nodes.
9. Any Line of Communication (LOC) interdiction that disrupts distribution for a specified amount of time.

Table 3. Logistics Information Requirements (after Joint Staff, 2013b; Schrady, 1998; USMC, 1997c; USMC, 1999; USMC, 2002)

The Marine Corps incorporated the Global Combat Support System-Marine Corps (GCSS-MC) Enterprise solution for combining the data streams relevant to supply and logistics information into one relational data warehouse. The goal of this overarching capability is to provide universal access and interoperability to information within the Marine Corps support functions (USMC, 1999). GCSS-MC is one of many Marine Corps Command and Control/Situational Awareness equipment modernization programs developed by Oracle USA Inc. Historically logistics data streams have not been integrated into a single distributed database, leading to difficulties integrating all logistics information into a single-source usable database schema. Differences in meta-data of the 16 significant logistics information systems currently in use are still causing difficulties in the integration efforts for GCSS-MC, but future development efforts are focused on achieving greater interoperability (USMC, 2014a).

The decision-maker uses relevant logistics and supply data during planning and execution as operations mature. At the Strategic level this information is contained in the Global Status of Resources and Training System (GSORTS) data and includes categories such as supplies on-hand and equipment status within the logistics realm (Schrady, 1998). Decision-makers at the MAGTF level require end-item status at much greater detail than GSORTS data provides. Major systems, ships, aircraft, and vehicles need to be broken out and defined in terms of mission capability: fully mission capable, partial mission capable, or not mission capable. Numeric percentages are important for the decision-maker and need to be incorporated as defaults for the visualization application. However, the mission capability of an asset, whether due to maintenance or supply, is not necessary for the decision-maker's immediate consideration, but should be accessible when requested as an option for the visualization application.

Sustainment stock levels are a crucial piece of information necessary for the decision-maker in planning operations. Projecting these levels in meaningful terms is essentially an algorithm, converting fuel in tons or pounds into days of supply (DoS) based on number of aircraft or sortie generation rates. These same types of algorithms can create DoS calculations for rations or ammunition supplies based on given rates of use. Planning factors never survive first contact with the enemy, nor are they highly predictable, therefore this is one area that benefits greatly by plotting forecasted rates against actual rates in order to determine trends and be proactive vice reactive.

Idealistically logistics decision support systems provide three major attributes for the decision-maker. First, a logistics based IS provides visibility on all assets in the joint environment. They deliver accurate and time sensitive information on location, movement, readiness, and identity of units, personnel, equipment, and supplies (USMC, 1999). Second, effective decision support tools would provide planners with capabilities such as "what-if" analysis of COAs, baseline comparisons to determine deviations during execution, and providing qualitative and quantitative values to logistics activities. Lastly, automated identification technology, such as bar codes, memory cards, and radio frequency tags, provide the most up to date information regarding location and movement status of property.

D. SUMMARY

Critical information requirements are essential elements of the decision support systems for the MEF decision-makers and planners. The information necessary for commanders and staff to conduct COA analysis and selection is a derivative of the information requirements designated as the PIRs and FFIRs. CCIRs derive responses that facilitate timely decision-making as well as improve the SOP of the organization. The CCIRs, nominated in the research, necessary for the decision-maker to create SA for himself/herself are abstract enough to fulfill the planning requirements and objectives for any major military operation.

Ultimately, PIRs and FFIRs integrate to create the SOP for the decision-maker. This SOP evolves throughout the hierarchical command structure as increased analysis is conducted upon the relevant information. Sharing the developments from this analysis transparently throughout the organizational structure increases the knowledge base and the SA of all echelons of the command hierarchy.

IV. THE DECISION SUPPORT SYSTEM

According to Shim et al. (2011), a decision support system (DSS) is "computer technology solution that can be used to support complex decision making and problem solving" (p. 111). The DSS aids the decision-maker in processing available data and formulating a decision. Modern technology has enabled the collection of multitudes of data; however, the utility of this data is derived from the user's ability to process the data into usable and relevant information from which to increase the situation awareness of the decision-maker. Gorry and Scott Morton (1971) argued that a decision-maker does not lack sufficient raw sensor data, but rather a decision-maker lacks a "method to understand and process readily available data" (p. 31) into information, knowledge, understanding, and wisdom. The struggle of the decision-maker to discern relevant information, from all available data sources, from which to base a decision is what Lowenthal (2003) has stated is the "wheat versus chaff problem" (p. 90).

The process of integrating raw data into graph entity relationships, when possible, is an initial phase of fusion requiring correlation techniques. The transitioning of integrated data into knowledge requires applying higher levels of fusion. The cognitive consumption of the results of fusion at different levels, results in understanding. Acting, or making decisions, on acquired understanding, contributes to the accumulation of experience. The post decision assessment of actions results in states of wisdom. Throughout the transition of data into higher levels of the DIKUW hierarchy, a DSS can assist the decision-maker by presenting visualizations that quickly and accurately build the decision-makers situation awareness.

A DSS can aid the decision-maker in processing available data. The DSS links the decision-maker to the raw live sensors and other authoritative sources stored in the data stores. These stores represent the physical world model (PWM). After the sensor data is correlated it is added to the knowledge base (KB), which reflects the states of the digital world model (DWM). The decision-maker is acting as a "human-in-the-loop" (p. 4) or a "human-on-the-loop," (p. 4) depending on the latency requirements of the executed workflows (Hawthorne & Scheidt, n.d.). This allows the decision-maker to supervise subsequent stages of fusion to generate mission-relevant knowledge. The decision-maker interacts with DWM through the DSS to glean required information and knowledge on which to base a decision. However, the decision-maker's success is dependent upon the rapid acquisition of relevant information from the DSS, in which the user's cognitive world model (CWM) is an accurate representation of the environment in which they operate. As the DSS becomes more predictive and prescriptive, the gap between the decision-maker's CWM and the DSS lessens. According to Hayes-Roth (2006), this sublimation process may be described as decision-makers and the DSS becoming "hyper-beings" (p. 6).

Though the DSS can benefit a decision-making process, the capabilities of the DSS are dependent upon the level of structure of the dynamic environment in which decision-maker operates. Problems facing a decision-maker can range in spectrum from unstructured (e.g. HUMINT, OSINT, documents), to structured (e.g., traditional sensors, METOC), to multi-structured pixelated data. A DSS aids the decision-maker in different capacities given the level of structure of the problem. Despite the structure of the problem, the user interaction with the DSS will govern the efficiency from which the decision-maker can glean useful and actionable information.

A. PROBLEM STRUCTURE

Given a situation, which requires a decision, the decision-maker is faced with an environment that has differing levels of *structure*. According to Gorry and Scott Morton (1971), "structure" refers to the level of autonomy a computer system can have in a decision-making process (p. 29). In a *structured* system, decisions can be automated and left for the DSS to make the decision. An example of a structured system would be a thermostat. A thermostat can make the decision to turn on or off a heater once a predetermined temperature is reached with little to no human input. An unstructured system, according to Gorry and Scott Morton (1971), is a system in which "the human decision-maker must provide judgment and evaluation as well as insights into the problem definition" (p. 26). The role of human supervision is to provide insight into the entropy that exists in the dynamic environment, which is outside the capabilities of the

DSS. In order for the DSS to be functional across a greater spectrum of structured systems, the DSS must be programmed with the similar adaptive workflows that the human decision-maker is afforded. Without this agility, the DSS is limited to a rigid set of constraints and logic in a dynamic, and constantly changing, environment.

The level of structure of the dynamic environment is dependent upon the level of structure of three interrelated categories. According to Simon (1960), these three categories are "intelligence, design, and choice" (p. 2). Young (1989) stated that by identifying the level of structure of each of the categories, the problem could be structurally categorized. According to Gorry and Scott Morton (1971) "a fully structured problem is one in which intelligence, design, and choice are highly structured" (p. 27). Jonas (2011) redefined these categories as follows (p. 100):

- "Sense and Respond" (Intelligence function): The stage in which the dynamic environment is scanned for pattern recognition and anomaly detection, and/or identification of opportunities that will require decisions to be made and implemented.
- "Report and Manage" (Fuse, Operational function): The stage in which possible courses of action which will compromise an alternative strategy are invented or otherwise generated or identified, developed, analyzed, and assessed for feasibility.
- "Explore and Reflect" (Integrated function): The stage in which one of the alternative strategies is selected (decided upon) and subsequently implemented.

Similar to the categorical components of intelligence, design, and choice; the level of structure associated with each of the Decision Theory Model components can determine the level of structure in the decision-making problem. According to Young (1989, p. 19-20) intelligence, design, and choice are replaced with the following Decision Theory Model components:

- "States of Nature: A combination of conditions (particular "settings") of the relevant variables, which are not controllable by the decision-maker (traditionally called "states of nature" although the conditions could be man-made by persons other than the decision-maker)."
- "Strategies: Alternative strategies, defined as courses of action or a particular combination of "settings" of the variables under the control of the decision-maker."

- “Outcome or Payoff: Interactions between each strategy and each state of nature that result in outcomes of importance to the decision-maker and which can be measured in some form of payoff units (often money).”
- “Relationship between Strategies, States of Nature, and Outcomes, Payoffs: A criterion of analysis rule by which a decision-maker can assess the situation and select a particular strategy.”

Young (1989) depicts categorizing a problem based upon the Decision Theory Model components in Figure 6.

a) The Decision Theory Model of a Decision Problem			
	"States of Nature" (Uncontrollable Conditions)		
Strategies	***N_1***	***N_2***	***N_3***
S_1	$\text{outcome}_{1,1}$ $\text{payoff}_{1,1}$	$\text{outcome}_{1,2}$ $\text{payoff}_{1,2}$	$\text{outcome}_{1,3}$ $\text{payoff}_{1,3}$
S_2	$\text{outcome}_{2,1}$ $\text{payoff}_{2,1}$	$\text{outcome}_{2,2}$ $\text{payoff}_{2,2}$	$\text{outcome}_{2,3}$ $\text{payoff}_{2,3}$
S_3	$\text{outcome}_{3,1}$ $\text{payoff}_{3,1}$	$\text{outcome}_{3,2}$ $\text{payoff}_{3,2}$	$\text{outcome}_{3,3}$ $\text{payoff}_{3,3}$

b) Degree of Structure in a Decision Problem			
Components of a decision problem	***Structured***	***Semi Structured***	***Unstructured***
Outcomes, payoffs	Identifiable	(some	unknown
Strategies	Definable	known, or	unknown
"States of Nature" (relevant uncontrollable conditions)	Known	estimated;	unknown
Relationships between Strategies, States of Nature, and Outcomes, payoffs	Known	some unknown.)	unknown

Figure 6. Decision Problem Matrix (from Young, 1989, p. 20).

Problem structure models by Gorry and Scott Morton (1971) and Young (1989) suggest that a problem of highly structured component variables equates to a highly structured problem. Given a highly structured problem, a DSS can operate at high levels of autonomy. The DSS can incorporate decision trees and algorithms in which to operate. Gorry and Scott Morton (1971) stated, "The Economic Order Quantity (EOQ) formula in an inventory control problem is an example of a highly structured decision-making problem, in which the DSS can work at high levels of autonomy" (p. 27).

Contrary to the highly structured problem, is a decision-making process in which the problem components are highly unstructured. Given a problem with unstructured components, human interaction is required in the decision-making process. According to Turban and Aronson (1998) an unstructured problem is one in which "the processes are fuzzy, complex problems for which there are not cut and dried solutions…where human intuition is often the basis for decision making" (p. 12). Turban and Aronson (1998) suggest examples of an unstructured process are "planning new services, hiring a new executive, or choosing between research and development projects for the upcoming year" (p. 12). In an unstructured problem, the flawless and efficient interaction of the user with the DSS is paramount.

It is important to note that the DSS is not intended to replace the human cognitive function of the decision-making process in an unstructured problem. In a structured problem, the role of the decision-maker is minimal; however, in an unstructured problem, the user's role is integral. In a highly structured problem, a DSS is highly autonomous with accurate models constructed that allow the DSS to achieve quantifiable objectives. However, in an unstructured problem; these objectives are less quantifiable and tangible; and user input is required. Given an unstructured problem, the DSS and the decision-maker (user) work in concert. Keen and Scott Morton (1978) argued that "Decision Support Systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions" (as cited in Turban & Aronson, 1998, p. 13). Whether the problem is structured or unstructured, the goal of the DSS, according to Young (1989) is the "increase (improvement, not optimization) in effectiveness in reaching ultimate objectives rather than mere processing efficiency" (p. 1).

The user's processing of information presented by the DSS is often the limiting factor of the decision-making process. This idea is refuted by Lowenthal (2003), who stated that computers (and DSSs) have "increased the ability to manipulate information, but the amount of derived intelligence has not increased space" (p. 80). Gorry and Scott Morton (1971) stated that *a DSS* "is an interactive computer based system, which help decision-makers utilize data and models to solve unstructured problems" (as cited in Turban & Aronson, 1998, p. 13). Furthermore, Young (1989) stated that a "DSS provide the means for interactive, user controlled, human-computer dialogues to help decision-makers cope with semi- structured (somewhat fuzzy) decision processes" (p. 1). The level of structure (unstructured vs. semi-structured) is indicative of the degree of uncertainty in the dynamic environment. Decreasing the gap between the user and the DWM, by introducing cognitive capabilities into the DWM, can mitigate this uncertainty.

B. COMPONENTS OF THE DECISION SUPPORT SYSTEM

The DSS has similar constructs whether the problem being addressed is a structured or unstructured problem. However, the role and responsibilities of the user in the DSS increase in an unstructured environment. According to Turban, Aronson, and Liang (as cited in Kamel, 2006, p. 12-13), the DSS is composed of the following subsystems:

- "Data management subsystem:
  - Includes database that contains relevant data for the situation and is managed by a database management system (DBMS) application.
  - Connected to the corporate data warehouse (with decision-making data) accessed via database web server."
- "Model management subsystem:
  - Software package that includes financial, statistical, management science, quantitative models providing analytical capabilities called Model Base Management System (MBMS) that usually runs on application server."
- "Knowledge-based management subsystem:
  - Support subsystem providing intelligence for decision-makers
  - Known as organizational knowledge base."
- "User interface subsystem"
  - Surface that enables "users to communicate and interact with the DSS."

    - “Interaction between users (decision-makers) and computing.”
    - “Web browser provides a user-friendly and easy interface.”
- The user
    - The decision-maker or individual utilizing the DSS.

Tripathi (2011) added to these components by linking the DSS to external entities such as “other computer based systems, internet, intranets, extranets, and organizational knowledge base” (p. 113). Trapathi (2011) depicts the components of a DSS in Figure 7.

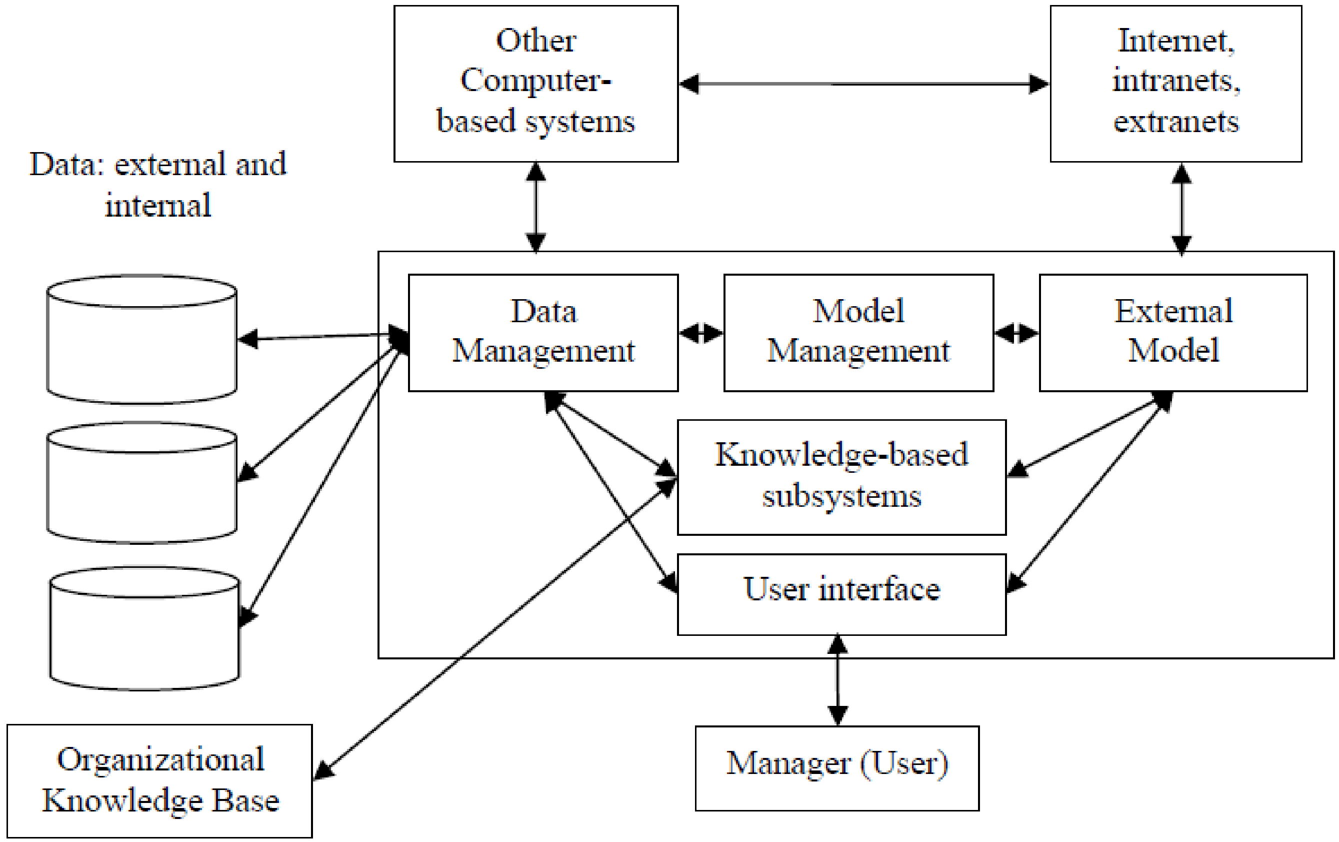

Figure 7. A Schematic View of a DSS (from Tripathi, 2011, p. 113)

In an unstructured problem, where the user has an integral role in the decision-making process, the link between the DSS and the user is the user interface. Gorry and Scott Morton (1971) and Young (1989), stated that in an unstructured problem, the DSS is an *interactive* system of which the user is an integral part of the DSS. Therefore, the full capability of the DSS is rooted in the efficiency and effectiveness in which the DSS can most accurately present relevant information and knowledge to the user. Visualizations provide the capability to ease cognitive perception in order to improve the veracity and quality of decisions. Henceforth, the most critical link in the DSS system is the communication link between the user and the DWM, or the user interface.

C. THE USER INTERFACE

The link between the user and the DSS is critical to the successful employment of the DSS. The interaction between the user and the DSS is bi-directional: it includes user inputs and requests, and the DSS return and display of the requested data. According to Sauter (2010), "to the decision maker, the user interface is the DSS" (p. 215). Turban and Aronson (1998) defined the user interface as "the hardware and software that facilitates communication and interaction between the user and the computer…including the exchange of graphic, acoustic, and tactile communication" (p. 229). Furthermore, Turban and Aronson (1998) stated that the user interface could be thought of as "a surface (lens) through which data is exchanged between user and computer" (p. 229).

The full capabilities of the DSS are limited by the link between the DSS and user. Sauter (2010) endorsed the importance of the user interface and stated:

> It does not matter how well the system performs; if the decision-maker cannot access models and data and peruse results, invoke assistance, share results, or in some other way interact with the system, then the system cannot provide decision support. In fact, if the interface does not meet their needs and expectations, decision-makers often will abandon use of the system entirely regardless of its modeling power or data availability. (p. 215)

Furthermore, Bennett (1986), states that the "quality of the interface…depends on what the user sees (or senses), what the user must know in order to understand what is sensed, and what actions the user can (or must) take to obtain needed results" (p. 355). In order to build a user's situation awareness, the user must know that a situation exists. Sensors that are linked to, or trigger the presence of, objects on the DSS, notify the user that a situation exists requiring their attention.

The interaction between the user and the DSS through the user interface is based on the mirrored exchange of data between the user and the user interface, and the user interface and the computer. The cyclical process of a user interacting with the DSS is illustrated in Figure 8 (Bennett, 1986). In this illustration the link between the DSS and the user (the user interface) is depicted. The processing power and capabilities of the computer are limited by the speed in which the user can orient and interpret the data that is presented by the DSS.

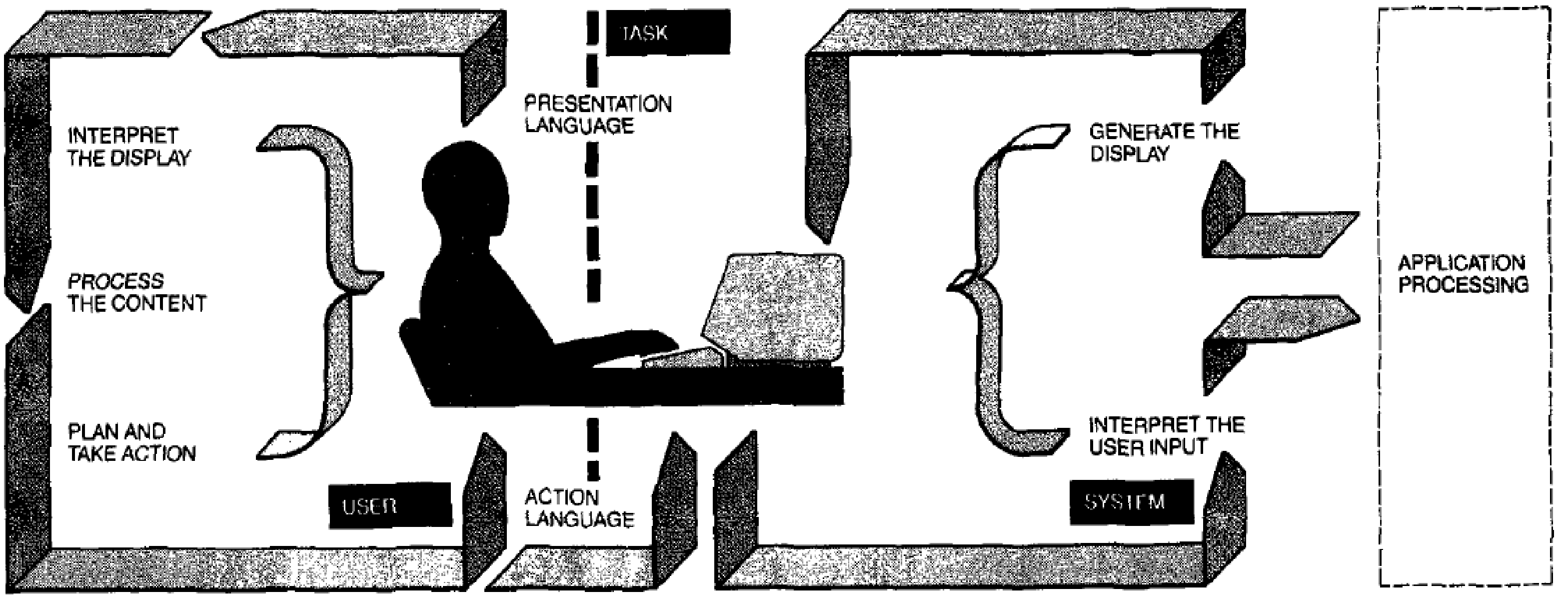

Figure 8. The Two Sides of the User Interface (from Bennett, 1998, p. 355)

The cyclical nature of the decision-making process occurs rapidly as the user interacts with the DSS through the user interface. Turban and Aronson (1998) defined this process as follows: “Displayed data provide a context for interaction and give cues for action by the user. The user formulates a response and takes an action. Data then passes back to the computer through the interface” (p. 230). According to Turban and Aronson (1998), the interactive process between the user and the system is depicted in Figure 9, and consists of the following components (Turban & Aronson, 1998, p. 230):

- “Knowledge: The information the user must have to communicate with the computer”
- “Dialog: An observable series of interchanges or interactions between the user and computer”
- “Action language: A user’s action language can take various forms, ranging from selecting an item from the menu (with a keystroke or mouse click), to answering a question, moving a display window, or typing in a command. Input devices are used to execute actions”
- “Computer: The computer interprets the user’s action (input), executes a task (such as computation or data access), and generates a display (the presentation language or the output of the computer)”
- “Presentation language: The information displayed to the users via output devices. Such information can be shown as display menus, windows, or text. It can be static or dynamic, numeric, or symbolic. It can appear visually on the monitor, presented as voice or a printout”
- “User’s reaction: The user interprets the display, processes the content, and plans an action”

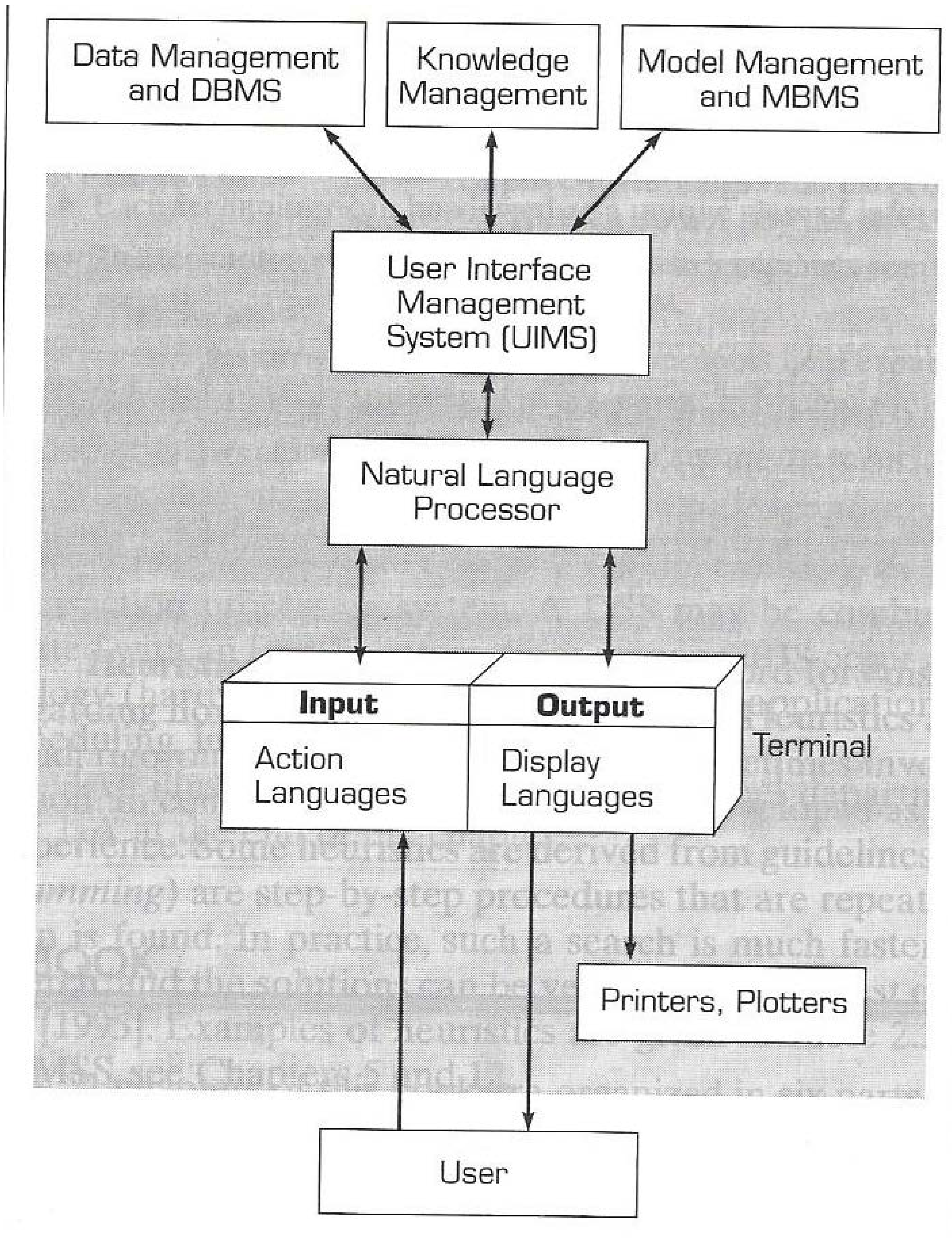

Figure 9. Schematic View of the User Interface System (from Turban & Aronson, 1998, p. 87)

Bennett (1986, p. 357) argued that a designer's goals in achieving a successful user interface are based on the following dimensions:

- "Learnability: A specified level of user performance is obtained by a required percentage of a sample of intended users within some specified time from beginning of user training"
- Throughput: The successful interaction by the user to quickly interact and acquire relevant information from the system.
- "Flexibility: For a range of environments, users can adapt the system to a new style of interaction as they change in skill or as the environment changes"
- "Attitude: Once the user has used the system, they want to continue to use it, and they find ways to expand their personal productivity through system use"

Developing a user interface that is easy to learn, minimizes errors, is flexible in scope, and is appealing to users, will greatly enhance the success of, and ease operational resistance toward the acceptance of the DSS.

The goal of a successful user interface is one in which Salter (2010) stated, "is a system that minimizes the barrier between human's cognitive model of what they want to accomplish, and the computer's understanding of the user's information requests" (p. 216). However, this interaction is limited because either the human, or the computer, may have a more accurate picture of the dynamic environment. In order to overcome the difference in the user's CWM and the computer's DWM, the DSS must be made fully aware of changes in mission phases and resultant states. Furthermore, the DSS must have the capability to discern if the user's queries are based upon a sub-optimal CWM of the dynamic environment and stream the DSS's most current SA. Therefore there is a requirement for two streams that are interacting to baseline the SA of the DSS (computer and user). These two streams, depicted in Figure 10, and compose the Human Computer Interface (HCI) Dataflow, are made up of the user's information requests and the KB response, and the streaming SA from the KB. The baseline of the CWM and the DWM becomes a prerequisite necessary for the users to avail themselves of the full potential of the system.

Ensuring that both the decision-maker and the DWM are operating at the same contextual mission state is paramount in providing the rapid acquisition of SA. Removing states of confusion regarding the baseline of SA will increase the velocity and veracity of decisions. Salter (2010) stated that the “prime concern is the speed at which decision-makers can glean available information from the system,” or more importantly, the highest quality of relevant information from the system. (p. 216). The user’s rapid cognition of the highest quality of relevant information from the system is what Salter (2010) describes as “exploiting the pre-attentive processing” of the user (p.216). According to Salter (2010), pre-attentive processing is the user’s ability to “recognize some attributes quite quickly, long before the rest of the brain is aware that is has perceived information” (p. 216). This supports what Bennett (1986) refers to as “learnability, throughput, and attitude” (p. 357). Further concerns facing the decision-maker include the time required to attain, the highest quality of relevant information and the confidence that the decision-maker has with their given level of situation awareness given a time constraint. This entails linking the decision-maker to the most timely and relevant information that is of acceptable quality on which to base a decision.

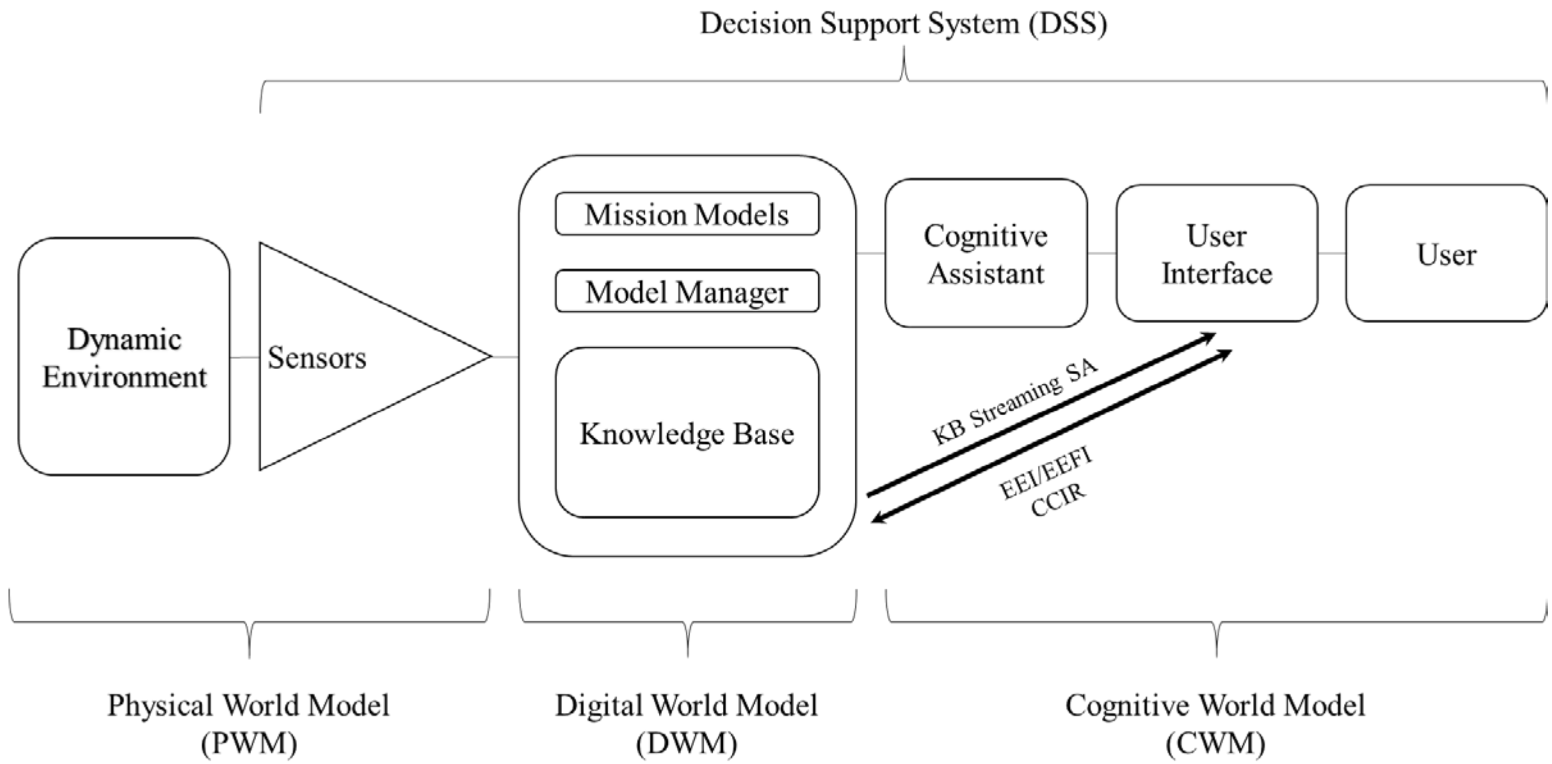

Figure 10. Human Computer Interface Dataflow

D. THE GRAPHICAL USER INTERFACE

An effective user interface is one in which the user interface can efficiently translate the action language of the user to the computer. An inability to clearly articulate a user information request (action language) to the computer will result in an inaccurate or irrelevant return (display language) by the computer. This breakdown of communication is indicative of a disparity between the situation awareness of the user and DWM, and can lead to a loss of trust and confidence in the DSS. Once the computer understands the user information request, it can complete the interaction by presenting the relevant data for the user to base a decision in a concise and easy to interpret display. According to Salter (2010), an effective user interface "makes information quickly apparent…and allows users to focus on the data and the models in a way that supports the decision" (p. 216). An effective method of DSS user input interaction, which minimizes interpretation errors and is easy to use, is through the use of a graphical user interface (GUI).

Given that time, and the commander's response time, is a constrained resource in a given operation, the more effectively and efficiently that a commander can orient and interact with the DSS is critical. If an operational commander is in a situation in a dynamic, constantly changing environment, as the situation unfolds, so does the mission context. Therefore, as events occur, the situation awareness of the user, and/or the DWM may be deficient. Therefore, the bi-directional interaction between the user and the DWM must build situation awareness as quickly as possible. The quicker that the decision-maker can effectively and efficiently interact and build the SA of the DSS as a whole (user and DWM), the decision-maker will be more apt to make a higher quality decision. Figure 11 demonstrates a graphical representation of this concept.

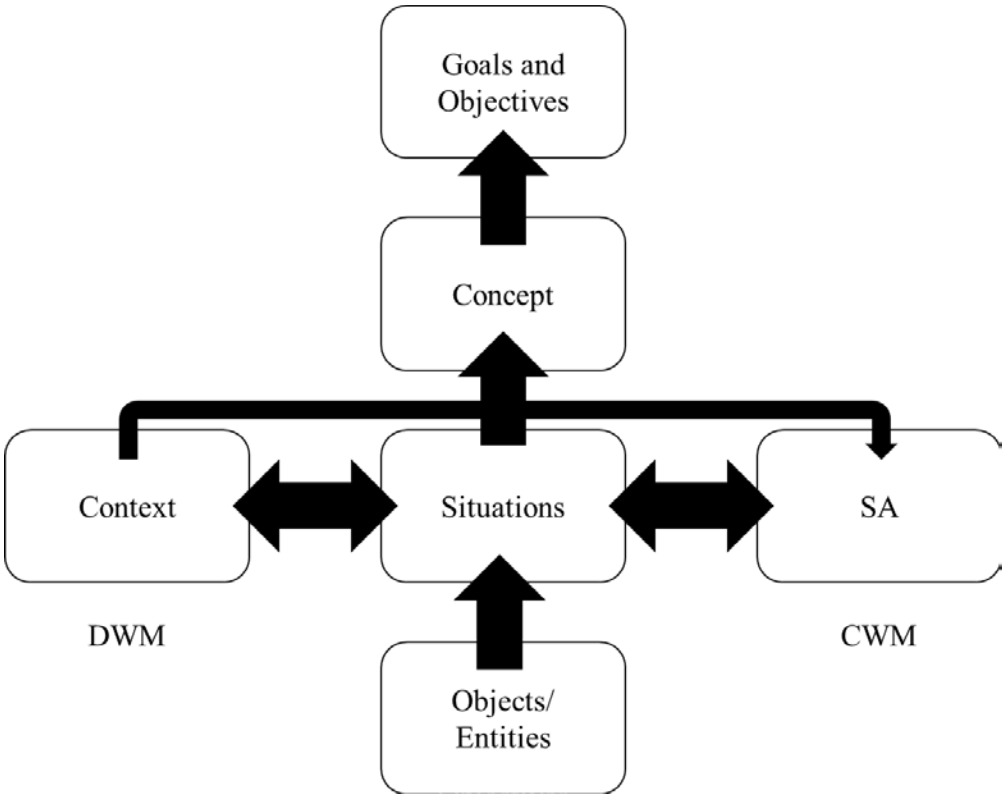

Figure 11. Interaction between the Digital and Cognitive World Models

A GUI, according to Turban and Aronson (1998), is an interactive user-friendly interface in which, by "manipulating objects, usually represented as icons (or symbols)," the user can interact with the computer" (p. 232). The GUI, according to Galitz (2007), is a method of user interaction with the DSS, in which the user utilizes an input device (mouse, microphone, touchpad), to interact with "elements referred to as objects…that are used to perform tasks such as pointing, selecting, and manipulating" (p. 15). The tasks performed by the user mimics physical reality, and can be easily translated into actions that the computer needs to perform. In other words, error and latency can by mitigated as the DWM more accurately represents the PWM.

A GUI increases user efficiency in the interaction with the DSS. According to Shneiderman (1982), stated that the benefit of a direct manipulation of the interface, or user interaction with the DWM, is based on the "visibility of the object of interest, rapid reversible actions, and replacement of complex command language syntax by direct manipulation of the object of interest" (p. 246). According to Galitz (2007, p. 18), the advantages and disadvantages of a graphical user interface are:

Advantages

- Symbols recognized faster than text
- Faster learning
- Faster use and problem solving
- Easier remembering
- More natural
- Exploits visual/spatial cues
- Fosters more concrete thinking
- Provides context
- Fewer errors
- Increased feeling of control
- Immediate feedback
- Predictable system responses
- Easily reversible actions
- Less anxiety concerning use
- More attractive
- May consume less space on the display medium
- Replaces national language
- Easily augmented with text displays
- Low typing requirements
- Smooth transition from command language system

Disadvantages

- Greater design complexity
- Learning still necessary
- Lack of experimentally-derived design guidelines
- Inconsistencies in techniques and terminology
- Working domain is the present
- Not always familiar
- Human comprehension limitations
- Window manipulation requirements
- Production limitations
- Inefficient for touch typists
- Not always the preferred style of interaction
- Not always the fastest style of interaction
- Increased chances of clutter and confusion
- May consume more screen space
- Hardware limitations

A well-designed GUI should be intuitively understood by the user in order to more quickly and efficiently translate user requirements into action language. According to Mingxia, Qichun, and Qi (2004), an effective GUI can replace the “complex and confusing syntactic and semantic language required to search through complex, multi-database environments” (p. 24). The utility of a well-designed GUI and user training, is in the ability of the user to proceed through their half of the DSS-user interaction yielding more actionable knowledge quicker. By narrowing the gap between the CWM and DWM, a user can attain the actionable information to base a decision quicker, or complete additional iterations until the desired level of situation awareness is achieved in a given period of time. Henceforth, the decision-maker can proceed through their cognitive decision-making cycle more rapidly.

E. GRAPHICAL VISUALIZATION

After the user interacts with the computer, and translates their information requests into action language, the computer can begin processing the information requests. The first iteration of the cyclical process is complete when the computer returns results via the display language. This can be in the form of a visual display on the display medium (monitor, mobile device, projection), a printout, or audible return. The ability of the user to quickly orient and process the graphic visualization will enable subsequent decision iterations to happen in a shorter amount of time. Furthermore, if higher degrees of understanding are attained from the visualization (Information, Knowledge, Wisdom), the frequency of reliance on the DSS to build an SOP will be minimized, since the decision-maker has the required level of knowledge to make a decision.

According to Galitz (2007) “visualization is the cognitive process that allows people to understand information that is difficult to perceive, because it is either too voluminous or too abstract” (p. 24). The goal of the visualization is to present user information requests in a manner that facilitates the rapid cognitive ingestion of wisdom from knowledge. This will enable the decision-maker to perform valuable analytics quickly on the visually presented data. Galitz (2007) stated:

> The goal of a visualization is not to reproduce a realistic graphical image, but to produce one that conveys the most relevant information. Effective visualizations can facilitate mental insights, increase productivity, and foster faster and more accurate use of data. (p. 24)

Furthermore, Sauter (2010) stated that a DSS (especially in an unstructured problem environment) "can facilitate intuition" by providing the decision-maker with the capabilities to know more than just the "results of an analytic model" (p. 48). Sauter (2010) stated that "presentation tools, such as graphs and charts, can ensure decision-makers grasp the full implications of their data…and see patterns among phenomena they might not otherwise notice" (p. 48). In order to provide anomalous detection, it is paramount that the DSS is capable of "illuminating trends, patterns, or anomalies, which are apparent only in graphical representations of the data" (p. 48).

A successful graphic visualization will quickly translate the *meaning* of the data to the user. Rather than just providing quantitative returns, the visualization of the DWM illicit user anomalous detection based on pattern identification. This allows quicker understanding of underlying themes, translation of data into information, and identification of decision implications on the status quo.

F. INFORMATION VISUALIZATION VERSUS KNOWLEDGE VISUALIZATION

In order to maximize the utility of a DSS, the user must efficiently interact with the system and quickly glean information from the computer's returns. Minimizing input errors can be accomplished through the direct manipulation of a GUI. However, this is only half of the interaction. In order to be able to quickly glean actionable information from the system, the user must be able to quickly orient and interpret presented visualizations.

The use of visualizations in a DSS can be grouped into the distinct categories of Information Visualization (IV) and Knowledge Visualization (KV). According to Frank and Drosodof (2005) IV is the "collecting of data, documentation of abstract database data…automatic visualization of big data masses and large quantities of information" (p. 365). IV is a topical presentation of data that lacks depth of introspection into underlying themes and patterns. According to Burkhard (2004), KV "is more than facts and graphs, its goal is an enabling technology allowing the correct conveyance and application of complex insights, experiences, perspectives, and high level concepts from one entity to another" (as cited in Hanratty, 2009, p. 3).

The optimal presentation for a DSS in a dynamic environment, requiring digital interoperability, is a KV. By presenting a user with an IV, the DSS is limiting the capabilities of the user. A KV will allow for a decision-maker's better understanding of the underlying themes behind the represented data. User's cognition of underlying variable interrelationships through a KV will grant the user an increased understanding than from the topical data visualizations presented in an IV. The user's increased cognitive state, or higher degree of situation awareness, will reduce the referential reliance on the DSS.

The goal of KV is the efficient transfer of knowledge, not data. According to the DIKUW framework, KV attempts to transfer data or information into knowledge and understanding. According to Burkhard (2004), in order for the transfer of knowledge to be accomplished the following "difficulties need to be solved" (p. 1):

- "Information Depth: Tradeoff between an overview and details that need to be communicated."
- "Limited Time: Limited time, attention, and capacity of the recipients."
- "Different Background: Different cognitive backgrounds and difficulties of decision-makers to understand the novel information visualization tools."
- "Relevance: Providing the relevant information to different stakeholders."

Despite the broad scope of data that needs to be encompassed in order to compete the successful transfer of knowledge, the KV needs to be focused to prevent common problems. These problems, according to Burkhard (2004, p. 1) are:

- Knowledge Overload: Decision-makers are not efficient in identifying relevant information.
- Misuse: Decision-makers cannot use or misuse the information for decision-making, or the knowledge presented is insufficient for the given level of uncertainty that exists in the dynamic environment.

The art of a KV design is being able to translate knowledge, through the user interaction, while minimizing the aforementioned pitfalls. If successful the KV will enable the user to understand, via cognitive perception, displayed information and knowledge quicker and more effectively. By transitioning to predictive and prescriptive recommendations, the KV will effectively minimize uncertainty, and the unknown, in order to maximize confidence in generated COA. The quicker data processing capability of the user will enable a more rapid progression through the user's decision-making cycle. Furthermore, the user will progress to higher levels of the DIKUW framework and reach higher states of dynamic unstructured environment understanding. According to Roth (2006) the seamless integration and sublimation of the DSS and the user is referred to as hyper-beings. Ultimately the higher understanding granted by the rapid translation of knowledge to the user will gain them a competitive advantage.

G. VISUALIZATION AND ANALYTICS

The use of visualizations will enable the decision-maker to gain deeper insight into raw data. This will allow a deeper understanding of underlying algorithmic models and decision variables that drive different outcomes. By reaching a deeper understanding of relationships that support a data model, the decision-maker will become less reactionary to the raw data. The overall goal of the visualization is to display the integrated data in mission's situation context managed by the knowledge base (KB). KB information and knowledge is stored in generated descriptive, predictive, and prescriptive layers by inference and other AI techniques. Commercial DSSs are transitioning toward predictive analytics, while the United States Marine Corps is focused on the use of visualizations that support descriptive analytics. Without overcoming the inertia that resists technological change, the United States Marine Corps will lack the competitive advantage that visualizations that support predictive analytics can provide.

H. DSS SOLUTIONS

1. Introduction to OLAP Cube and OLAP Cube as an Integration Layer

As defined by the OLAP Council (1997), OLAP is a data integration model that allows users to analyze integrated data via fast, consistent, interactive access to numerous views of information. OLAP supports workflows and dataflows starting from raw data to reflect multidimensionality and individual dimension's hierarchical relationships. Colliat (1996) further adds that OLAP service tools provide analysis methods for databases. These analysis methods possess historical, current, and projected summary data characteristics at the most basic level. Additional analysis features include multiple level interactive navigation, derivative data views from raw data, multidimensional views, near instantaneous gap analysis, and large datasets (up to 500 Gigabytes). Colliat's (1996) research also proves that multidimensional database representations provide significant advantages to relational database formats with respect to used storage space, speed of retrieval, and derivative calculation speed with less investment of time achieving better results with more capable query analysis.

The OLAP cube provides an extraordinary opportunity to support transparency in a SOP. Data integration and data fusion reduces the data saturation of the decision-maker and enables rapid building of a SOP, provided the data is handled with appropriate information aggregation techniques by leveraging OLAP dimension hierarchies. OLAP data model presents an optimal environment for the DWM to extract the necessary knowledge through the exploitation of the OLAP cube and is a good foundation for analytical modeling.

Figure 12 depicts the OLAP data cube concept and the functionality it implies for the decision-maker to extract pertinent data from the source cube. The source cube is the data warehouse or master data repository, organized for faster data access, containing all available data views. The smaller cubes or segments are disseminated to the decision-maker by knowing what is pertinent to him/her. Possessing only the relevant data reduces network bandwidth requirements while improving latency in query retrieval. It also enables traceable origins, or provenance, of the analytics and confirms the derivation of the source of data for the decision-maker, which is paramount to securing a competitive advantage. A greater understanding of the pedigree of data generates trustworthiness within the decision-maker regarding the data's authenticity and integrity.

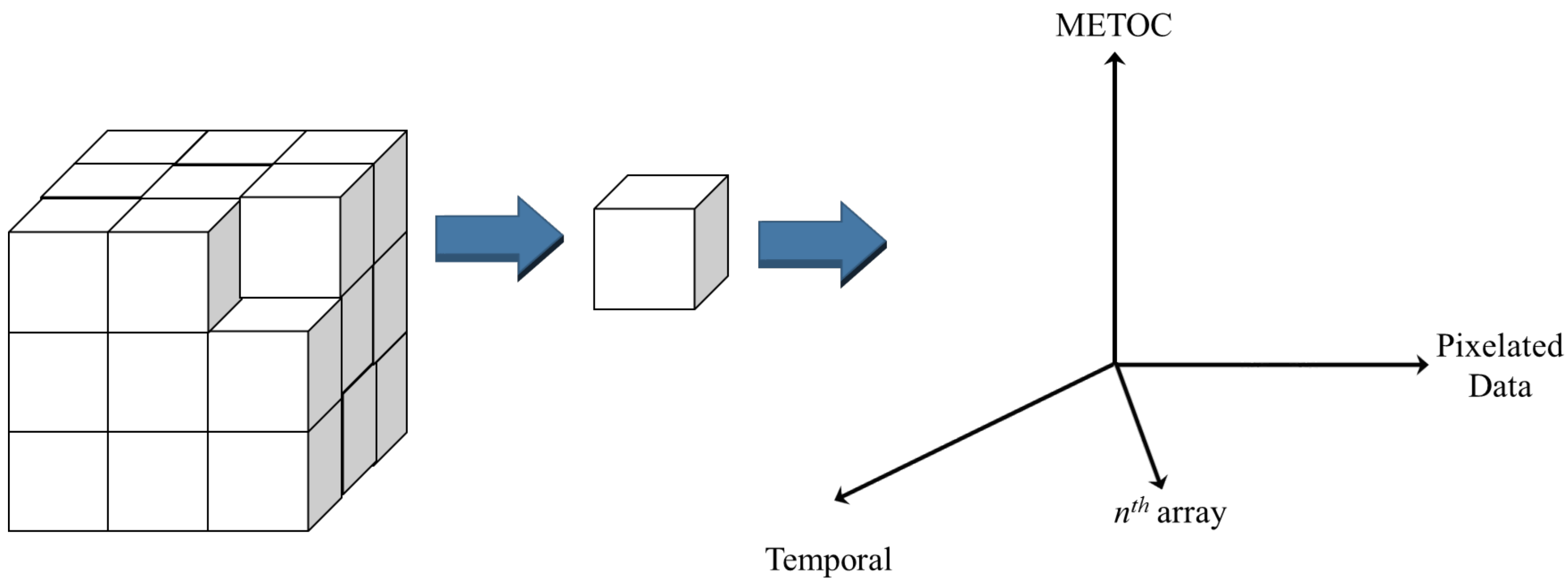

Figure 12. OLAP Source Cube Propagation Model

The OLAP cube architecture is valuable as a metadata management layer for incorporation into the proposed model for DSS and knowledge view management. The user at any hierarchical echelon level including the tactical edge dissects the master cube depicted in Figure 12 further, utilizing intuitive navigation query techniques to negotiate the meta-data. This allows the user at the tactical edge to be operational in limited to zero bandwidth scenarios. Decision-makers interactively execute the OLAP Cube aggregation/summarization operators over the data views. This concept is presented in Figure 13. The decision-maker is enabled manipulation over the cube layers with slice-and-dice, roll-up, or drill-down actions on the meta-data to exploit the cube model looking for the pertinent data at his/her decision making command level.

The decision-maker can then utilize prior views already located within the data storage array to create derived views based on his selections provided to the aggregation/summarization operators. This architecture supports arrays that can contain any data type, except unstructured data. Such approaches make it possible for the decision-maker to extract the knowledge (captured in the views) as part of the HCI DSS exploitation process. Due to the *unstructured data* limitation unstructured text is interpreted and stored in the same venue as operational commands. The holistic view of the general data flow is further developed in the analysis section Decision Support System section.

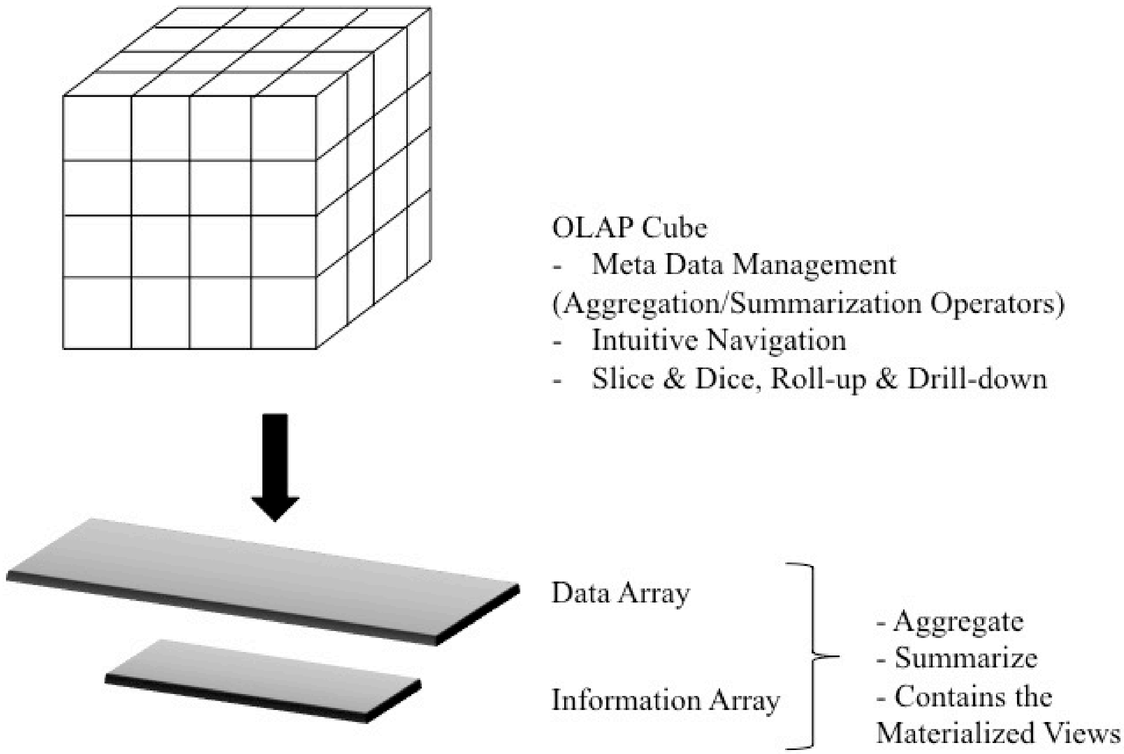

Figure 13. OLAP Cube as an Integration Layer

2. OLAP Cube Use Cases

a. Operational Statistical Analysis

The Google Public Data Explorer (GPDE) utilizes the OLAP data cube to visualize published statistical data (W3C, 2013). The specific language utilized for the visualization and exploration of the statistical data is the Dataset Publishing Language (DSPL), which combines the tabular number and text data in comma-separated value (CSV) files, the data schema, and XML files (W3C, 2013). This particular use case demonstrates great relevance for military use of the OLAP Cube architecture based on comprehensible visual depictions and ease of data exploration of the graphical visualizations. Unit logistical statistics and readiness rates compared over user-selected ranges would enable commanders to comprehend the situation with the appropriate visualization model that most closely reflects the DWM. The OLAP Cube architecture allows for the data to be hierarchically organized and then the user the opportunity for drill-up and drill-down as appropriate.

b. Sensor Integration and Analysis

Another OLAP Cube architecture use case with attributes beneficial for the decision-maker involves aggregating raw sensor data. Typically this data is published on the Web and visualized inside a webpage. Environmental data is of particular interest to military commanders, measured via autonomous sensors and assimilated into XML files on the Web and integrated and displayed together. From this data, with aid from the digital assistant available through the DSS, the user can manipulate the meta-data within the OLAP Cube in order to create a visual representation of the data. Through further manipulation of the stored data the user can adjust the visual representation as well as create new representations by combining other views or creating brand new views. Presentations of the queried data ranges from complex to simple depending on the application attribute selections of the user or the cognitive capability of the decision-maker based on inputs from the cognitive assistant.

3. Non-cloud Based

A technique for incorporating text-rich type documents into searchable database architectures is the Contextualized Data Warehouse Architecture (CDWA). This is an interim step, developed in parallel with ongoing tactical data cloud efforts in the Navy and Marine Corps utilizing OLAP Cube and the Relevance Cube (R-cube) data warehousing technologies. The contextualized data warehouse architecture structure is a non-cloud-based decision support system that combines structured data and unstructured text-rich documents into usable information by analyzing integrated data under context (Perez, Berlanga, Aramuru, & Pedersen, 2005). The analysis of both structured and unstructured data is valuable to the commander. Figure 14 depicts the flow of structured and unstructured data in parallel, emphasizing the extraction of contextualized facts from text documentation and combining this information with structured data from an OLAP tool, providing robust analysis of all information resources for the decision-maker that is easily assimilated into an information system for display to the commander.

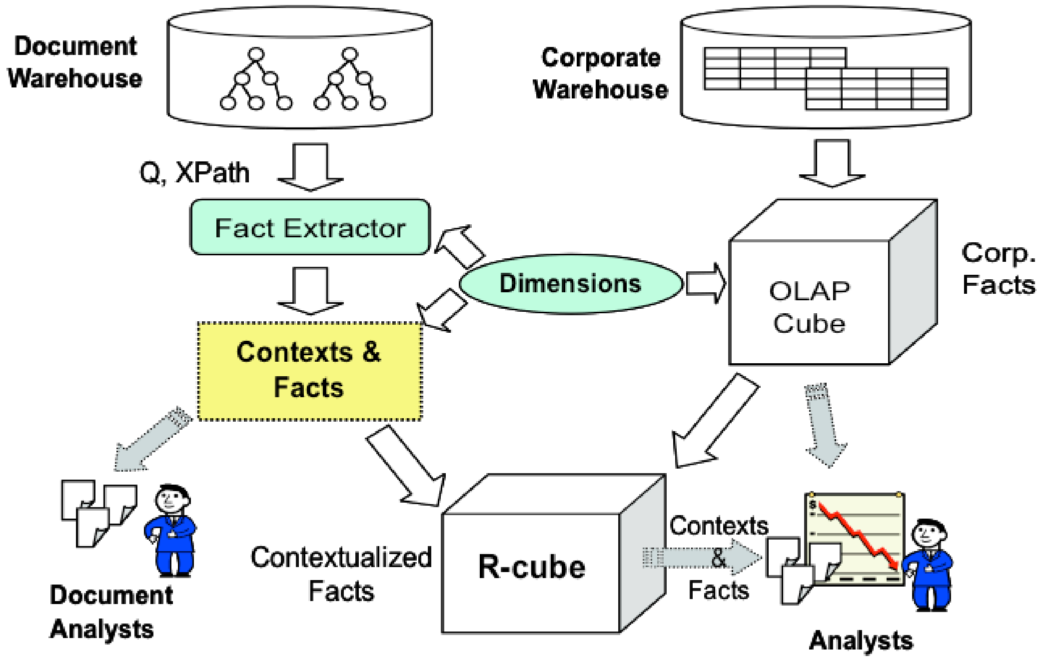

Figure 14. Contextualized Warehouse Architecture (from Perez et al., 2005)

The foundation of the contextualized data warehouse architecture, as depicted in Figure 14, contains the main components of the traditional structured data warehouse, represented as the Corporate Warehouse, and a document warehouse, able to evaluate designed information retrieval conditions. Additionally depicted are the fact extractor module and the OLAP component, which feed data into the relevance cube (R-cube). This architecture better supports the text-rich data inherent with intelligence reports by extracting the pertinent data elements from the documentation based on dimensional inputs providing context for extrapolation. The focused inputs are derived from the essential information requirements, such as CCIRs, established by the decision-maker.

Perez et al. (2005) developed a technique that combines the structured data of relational or multidimensional databases, easily analyzed via OLAP tools, with unstructured data from rich text documents, where information extraction techniques identify facts from the document with relevance to the key word searches. This type of data architecture allows decision-makers to incorporate unstructured data thoroughly into their decision-making processes. The analysis is performed by an R-cube, which is characterized by the two dimensions of relevance and context (Perez et al., 2005). Perez et al. (2005) define these two dimensions as the numeric value relevance, which measures the importance of each extracted data fact in context with the analysis, and the context relating the facts to the documents explaining the facts circumstances.

A user supplies a sequence of key words for the search, such as *ISIS critical vulnerabilities*, which is analyzed for relevance against the text-rich data pulled from the document warehouse via the fact extractor. The information is analyzed with the R-cube, and segments of the text-rich documents are provided based on a relevance value with regard to the context of the search keywords (Perez et al., 2007). The R-cube analyzes only the text-rich data available via the fact extractor algorithms to locate pertinent information to the user in a condensed format, displaying only relevant lines of analysis improving the timeliness of a Commander's decision-making process.

These data warehousing models provide robust capabilities for social network analysts' keyword searches sifting through vast amounts of data without any real analysis capability and are ideal for the text-rich XML and JSON documents, but are neither the software solutions, nor architecture of choice for the current Tactical Cloud Reference Implementation (TCRI). The main reason for TCRI not incorporating Contextualized Data Warehouse is because the TCRI database is based on Accumulo NoSQL data store. Dimension definitions of the Contextualized Data Warehouse are not a direction currently pursued by TCRI generalized schemas, as TCRI's emphasis is currently to support Semantic Web Standards based on OWL/RDFS technologies. Those standards don't follow multi-dimensional school of thinking as Data Warehouse do. The latter is based on OLAP data model, while the former is not. There are novel efforts to include OLAP data cubes into the Hadoop ecosystem. However, those efforts are focused on integration with Hadoop Distributed File System (HDFS) without any integration with Accumulo-based Knowledge Stores based on OWL/RDF.

4. Cloud Based

The Apache Software Foundation (2015) distributes Apache Hadoop, open-source software framework solutions, for distributed computing that is reliable and scalable. The software is capable of analyzing large data sets and distributing over thousands of machines within a cluster. Data storage is controlled by the Hadoop Distributed File System (HDFS) and data processing is accomplished with Hadoop MapReduce. An additional software package building on the HDFS, with easier user interface and greater speed, is Apache Berkeley Data Analytics Stack (BDAS). BDAS is an open source software stack that integrates software components that are active contributors for developing the framework of machine learning (ML).

ML provides other key attributes for big data processing, such as dimensionality reduction and decision trees. Via ML techniques variables are eliminated from consideration based on redundancy or irrelevancy improving performance. For example, in kinetic attack planning scenarios, time and location may be critical operational factors, however, in non-kinetic scenarios, such as cyber warfare, physical location may be irrelevant. Decision trees are useful ML method for evaluating multiple COAs through maximization of expected outcomes. Another ML technique is combinatorial optimization, including simple random sampling and heuristic and statistics-based approaches, allowing software algorithms to group similar COA and find the operationally *best* alternative (Schrijver, 2002).

Similar to Hadoop MapReduce, Spark is a ML framework that utilizes an improved application program interface (API) based on a resilient distributed data (RDD) set container that supports lineage and provenance. The interaction of Spark with other Hadoop tools for interactive queries, large-scale graph processing, and real-time analysis, enables processing and querying of big data (Apache, 2015). Novel approaches utilizing Apache Spark in cloud architecture, enables analysis of COA decisions based on OLAP Cube risk mitigation techniques. By leveraging the ML, Spark provides the capability of dynamically creating rules adapting quickly to changing environments and scenarios. Additional Apache software, such as Spark Streaming (Apache, 2015), provides real-time updates based on *micro-batch* processing, sampling incoming data by small time windows or batches, while sacrificing some latency for efficiency and resiliency. The key to success is selecting the appropriate algorithms for the different operational, intelligence, and logistics data type combinations and the requested outputs.

I. CURRENT DSS EXAMPLES

Many commercial DSS exist that help commercial organizations yield a competitive advantage. For example, United Parcel Service (UPS) employs a DSS referred to as ORION (On Road Integrated Optimization and Navigation). This DSS provides visualizations that enable predictive analytics for UPS logistics support. Since the inception of ORION, UPS has had a reduction in 85 million miles driven, 8 million gallons of fuel purchased, and 85,000 metric tons of carbon dioxide released into the environment (UPS loves logistics…and analytics, n.d.). Furthermore, these reductions have translated into a reduction in operational costs, which have been translated into customer value as UPS accomplishes their mission more efficiently (UPS loves logistics…and analytics, n.d.).

Aside from UPS, the financial sector has also adopted DSS that provide visualizations and predictive analytics. From a decision-maker's perspective, Burg (2015) stated that "financial services companies have decreased the time to decision time by 13%...utilizing analytics to aid in the decision making in areas of risk, fraud mitigation, liquidity, and collateral management" (paragraph 8.).

Though UPS and the financial sector have experienced the benefits of a predictive and prescriptive DSS, the United States military services have yet to incorporate such systems. The task of incorporating such a DSS into the military organization will be very challenging because the DoD maintains such a wide variety of Big Data. The current hierarchal architecture of the DOD has caused a hierarchal organization of physical and data workflows. Due to the hierarchal nature of the DOD, this is an inevitable reality. Until the physical and data workflows can transcend this architecture, the full benefits of a prescriptive or predictive DSS will be unattainable. Achieving this level of data integration will take a vast investment of time and work. Both UPS and the financial sector have achieved these benefits relatively quickly. The DOD will have a harder time achieving these benefits because the mission scope UPS and the financial sector is more focused. The battlefield commander requires integrated physical and data workflows that encompass the entire DOD and their associated entity mission scopes.

J. SUMMARY

A decision-maker is subject to the limitations of their cognitive capabilities while trying to maintain situational awareness in a dynamic environment. Whether in garrison or on the tactical edge of combat, a myriad of sensors are collecting a mass of data that the decision-maker is unable to process and comprehend. A decision support system provides the decision-maker with an interactive tool that enables them to have a higher degree of SA of the dynamic environment in which they operate.

As the design and functionality of DSS components are improved, and data across the organization becomes increasingly integrated; the gap between the decision-maker's CWM and the PWM, decreases. As this gap decreases, the decision-maker is able to orient himself/herself to the environment with increased veracity and velocity. This heightened SA, which is more accurate, yields higher quality decisions.

Enabling the rapid building of a decision-maker's SA is dependent upon linking the DSS to the most accurate and relevant data. Visualizations based on OLAP cube integration, provide the opportunity for the decision-maker to rapidly glean knowledge from the DSS. Utilizing visualizations based on OLAP cube integrated data will build the situation context that is managed by the DSS knowledge base. As the KB increases, the DSS will transform from a system that is descriptive, to one that is predictive, and ultimately prescriptive system. The greatest benefit, and competitive advantage, is achieved from an organization that embraces a prescriptive DSS based on an integrated data source.

V. ANALYSIS

The United States Marine Corps has a storied history of being able to adapt to the environment, overcome adversity, and rapidly manipulate procedures to contend with unforeseen environmental challenges and novel belligerents in order to accomplish the given mission. However, the Marine Corps' success does not directly correlate to the achievement of effective and efficient mission execution. Often the organizational structure of the service is a hindrance to efficiency. Sometimes effectiveness in mission execution is deterred by information degradation and lateness in the doctrinal reporting structure. The concept of merging process and data workflows, performing data analysis, and overcoming the traditional hierarchal reporting architecture of the Marine Corps, will create greater transparency, effectiveness, and efficiency for the organization.

Information is essential to the efficient execution of mission orders in combat. Information is derived from FFIRs and PIRs, which stem from a decision-maker and the SA inherent within the commander or appropriated from the support systems. Two major utilities derive the effectiveness and efficiency of the C2ISR and Logistics support functions within the military service: workflow and dataflow provenances. The former is a function of organizational structure and military processes (TTPs, SOPs, etc.) and the latter is a function of authoritative source data granularity within the architecture.

A. USMC ORGANIZATIONAL STRUCTURE

1. As-is Hierarchical Structure

The hierarchal structure of the Marine Corps is susceptible to the construct of organizational silos. This hierarchal structure benefits the Marine Corps Commander based on the relative ease of control and manageability; however, it imposes limits upon achieving integrated organizational efficiencies and effectiveness. The hierarchal structure of a Marine Expeditionary Force (MEF), the basic building structure of the Marine Corps, is depicted in Figure 15.

The top of the organization is the command element (CE), which is composed of the MAGTF Commander and the headquarters staff. The primary elements that make up the MEF are the aviation combat element (ACE), ground combat element (GCE), and the combat service support element (CSSE). The aviation element contains all aviation assets and the supporting structure. The GCE contains the ground forces, mechanized and non-mechanized, which are available to the MAGTF Commander for combat operations. The primary infantry unit of the GCE ranges from a division to a battalion based upon the mission of the MEF. The infantry units are based on the four-man fire team, three of which make up a squad. The rule of threes continues up through the organizational structure of the platoon, company, and battalion. The CSSE handles the logistics functions of the MEF and is responsible for supporting both the ACE and the GCE.

During combat, and while in garrison, higher headquarters dictates an overriding mission objective to subordinate units along with a Commander's Intent, or more generally, a desired end state. This command philosophy allows the subordinate commanders to decide how to achieve their portion of the mission. The principal mission objective focuses the individual units on achieving short-term goals, without regard to surrounding unit's tribulations, often to the detriment of attaining organizational effectiveness and efficiencies. In pursuit of parallel objectives, a commander splits his or her forces requiring a very high level of SA to maintain the mission context.

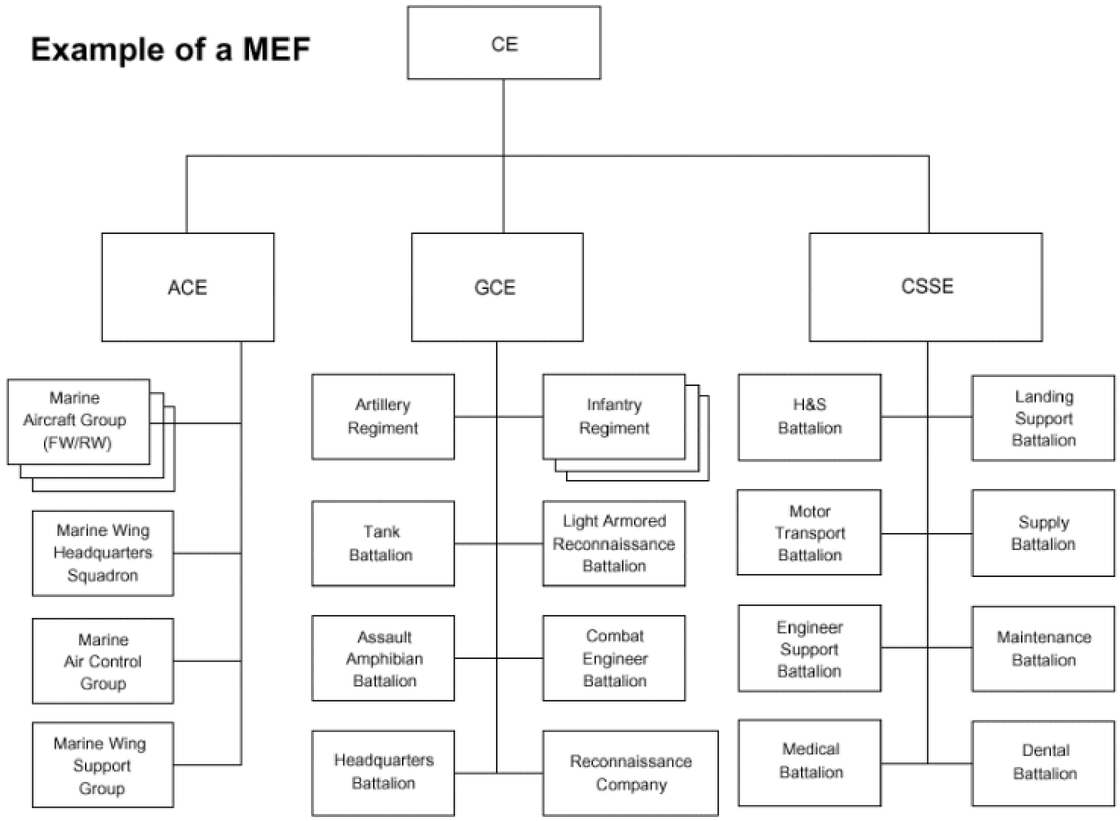

Figure 15. Marine Expeditionary Force (MEF) Organizational Structure (from MCDP 3, 1998)

The organizational limitations imposed by the hierarchal stovepipes of this structure create near-sightedness or the individual entities toward their portion of the overall mission only. Most units do not comprehend the complete impact their individual efforts have throughout the organization and on the overall ethos. The Commander's attentions are focused on the individual process workflows that the unit must embody in order to achieve unit effectiveness; this structural linchpin, fashioned by doctrine, inhibits integrated process and data workflows throughout the larger organization. This concerning dilemma is readily apparent in the current construct of CCIRs, both FFIRs and PIRs.

Each individual unit commander formulates CCIRs in order to act as notification triggers to environmental changes and commander expectations during the execution of the operation to attempt to keep the commander's SA within a given confidence level. Upon notification of a CCIR, the commander orients cognitively to the situation, and makes the necessary decisions based on the available information and their understanding of the given dilemma. This type of system process is highly reactionary; the commander receives the notification, achieves some semblance of SA, and reacts to the situation accordingly. In order to achieve a higher degree of efficiency and effectiveness in command and control, an integrated information system needs to be created.

The CSSE is responsible for handling the logistics functions of the entire organization and the workflows associated with the CSSE are integrated heavily with the workflows of the ACE and GCE. As the ACE and GCE use resources, a demand signal is sent to the CSSE to replenish those supplies. Maintaining a heavy surplus of supply is not an ideal situation for military forces forward deployed in austere environments. The synergy of resource replenishment and utilization is preserved based on the dataflow between the ACE and GCE units with the CSSE. When specific thresholds, encoded into rules, are triggered; the CCIR notifies the commander prompting them to make decisions.

The informational transference architecture of a MEF is depicted in Figure 16. FFIRs and PIRs act as an iterative feedback loop between the decision-maker and the dynamic environment in which they operate. A commander formulates a decision and issues an order. If the given situation progresses in a manner other than anticipated, a CCIR is triggered, in the ideal system, in order to notify the commander; and thus complete the feedback loop. If the commander is unable, or only partially able, to address the CCIR, the decision point passes to the subsequent higher echelon in the command hierarchy.

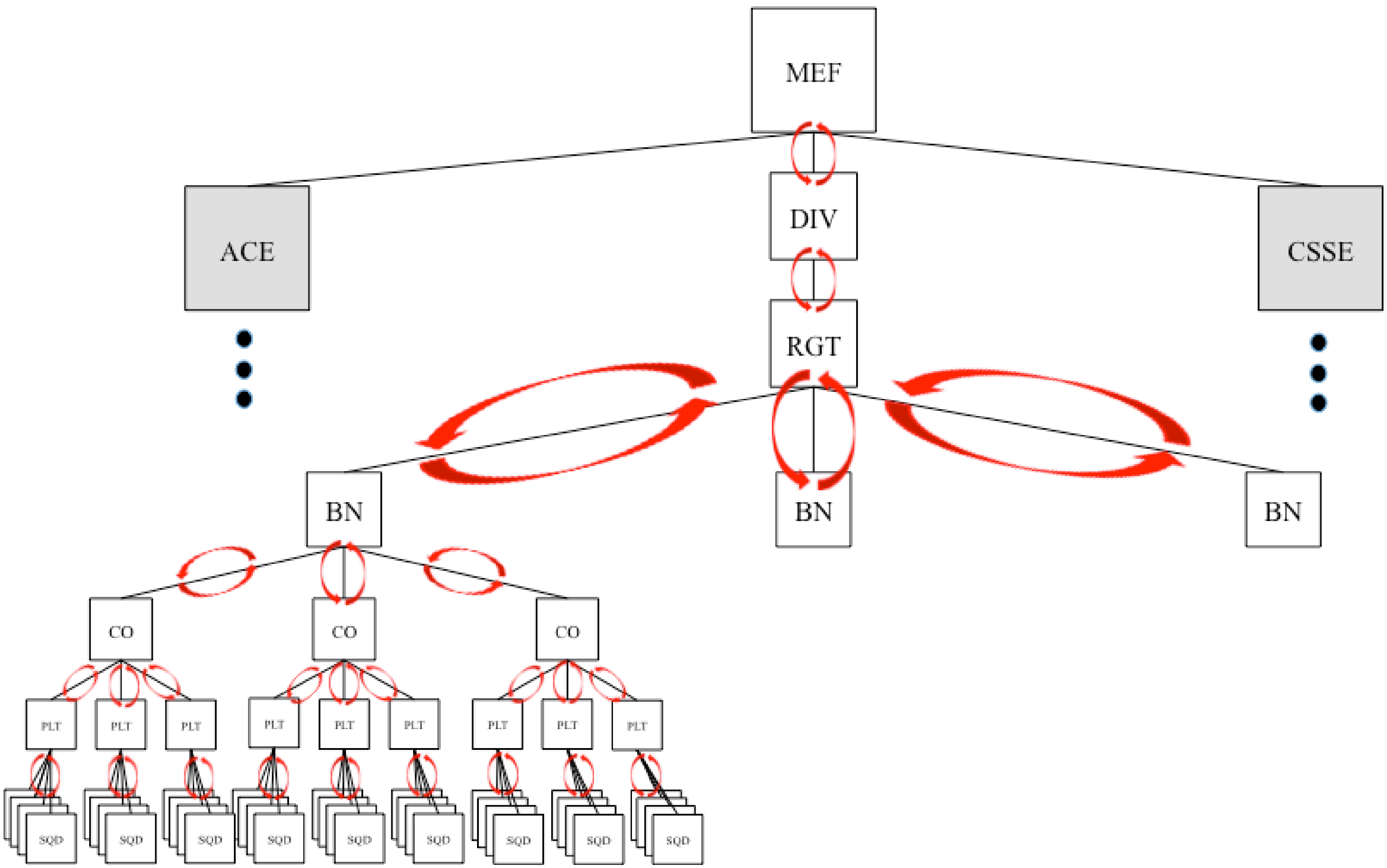

Figure 16. MEF Hierarchical Command Structure with Non-integrated Feedback Loops (As-is) (after MCDP 3, 1998)

Often, subordinate CCIRs are based upon CCIRs formulated from higher headquarters. Therefore, what a higher commander deems important, becomes a CCIR for a subsequent commander, limiting the agility of subordinate commanders to proactively adjust CCIRs based on their units given environment. The construct of FFIRs and PIRs are limited to the SA of the superior decision-maker. Therefore, the level of SA of the superior commander has cascading effects on the subordinate echelon SA and the organizational SOP. The hierarchal structure of the MEF is therefore an information architecture based upon a pyramid of feedback loops, FFIRs, or PIRs. Reports, in response to FFIRs and PIRs, forward information up the chain of command as a situation evolves, while new orders ripple back down the chain of command as higher echelons of command make the required adjustments. Due to this organizational hierarchy, error and/or information latency is introduced into the decision-making system at each level of the hierarchy.

The error and/or latency introduced into the feedback system can have cascading effects on the higher echelon decision-maker. Each hierarchal level has the potential to introduce additional error or latency on the information based upon the lens of interpretation, therefore affecting the overall SA and SOP of the organization. In order to yield increased operational agility, and competitive advantage, the flow of information needs to change. Instead of processing information linearly throughout the hierarchical organization structure, a concurrent dataflow, needs to be in place. This concurrent dataflow translates priority information (FFIRs and PIRs) instantaneously throughout the organization. The linearity of reporting is removed and lateral information sharing is achieved. This type of informational architecture would resemble a matrix of information sharing nodes all inter-connected and autonomous, vice a hierarchal organizational structure as depicted by Figure 16.

2. To-be Integrated Matrix Structure

The ideal data sharing organizational structure is described as a matrix comprised of interconnected and autonomous nodes integrating data from every sensor, to every node, and to respective decision-makers in a matrix of interconnectivity as depicted in

Figure 17. By using the OLAP data model for achieving an organizational SOP, SA is integrated laterally and vertically throughout the hierarchal command structure. Linking the data to the decision-maker (D2D) minimizes error induction and latency, and therefore increases the overall efficiency and SA of the organization participants. The interconnectivity increases transparency of organizational decisions and strategy. A matrix of integrated information workflows will yield many benefits to the commander. However, the increased volume of information to the tactical edge easily leads to information overload at the sub-commander level.

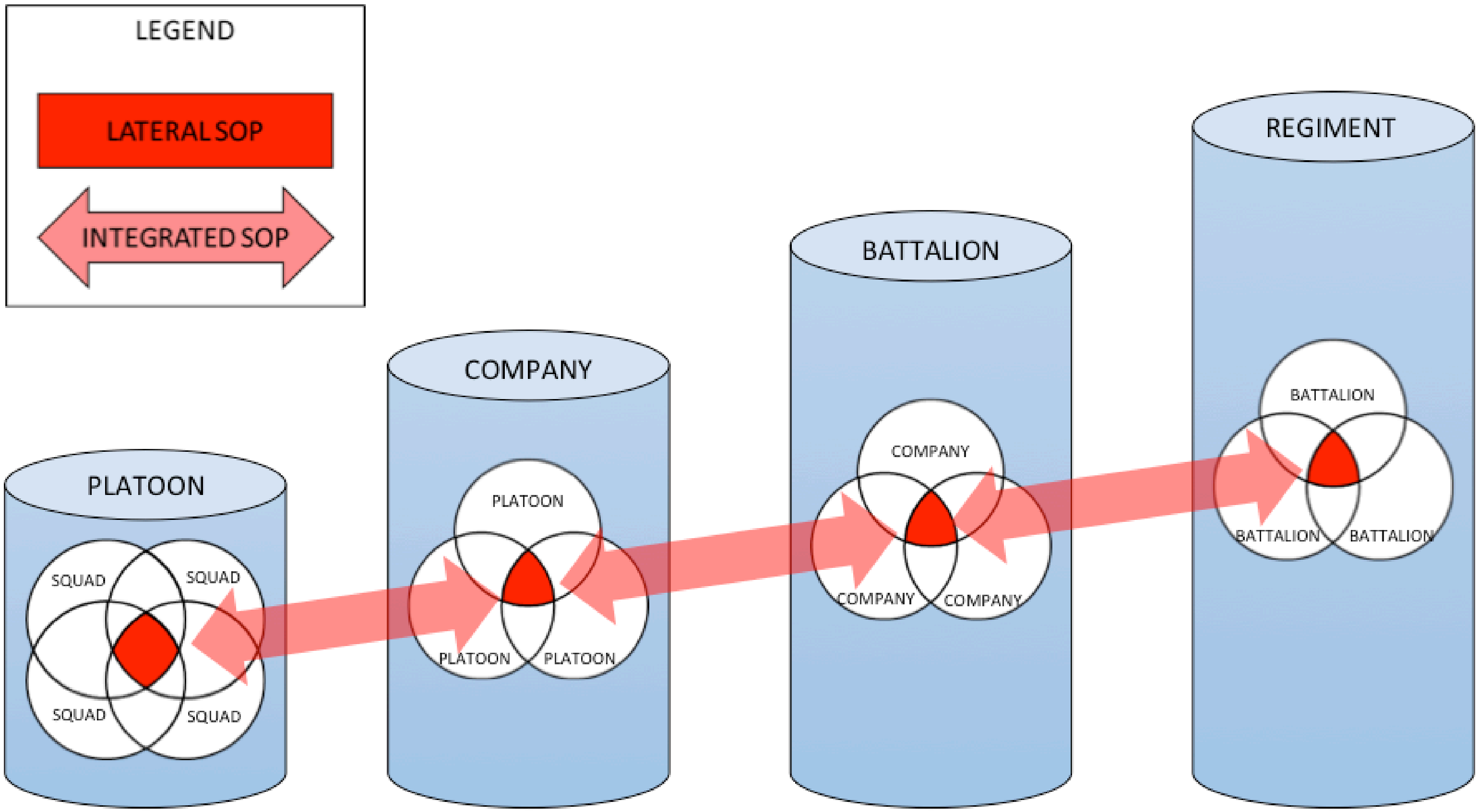

Figure 17. MEF Hierarchical Command Structure with Integrated Decision Points (To-be)

Veracity of information and velocity of quality decisions will yield the commander a competitive advantage. Commands that are lower on the MEF command hierarchy have higher velocity of decision cycles than superior echelon commands. This will ensure that over time, after the performance of analysis on the dataflows, the holistic organization becomes more efficient and effective in day-to-day operations. In the Marine Corps these benefits may be unattainable, as this type of organizational change will be faced with active and passive resistance due to cultural inertia and organizational bias. Straying from the traditional means of information sharing to a more transparent integrated information matrix threaten commander's occupational status and job security.

Increased availability of sensor data, via transparent access, may produce negative impacts on the control a decision-maker possesses. Transparency of the information management is a powerful tool for leaders to exercise control over subordinates. In order to shape the situation senior commanders might find a necessity to withhold certain information from a subordinate in an effort to manipulate actions and achieve a particular outcome. While difficult to understand the utility of this practice, the matrix organizational structure would eliminate the ability to manipulate available information based on a superior commander's bias.

In another instance, a subordinate commander might find it beneficial to withhold information from the superior commander. The matrix structure provides the superior commander tools to see through those efforts. Therefore, a subordinate commander withholding information contradicts the superior commander's SA. For example, a subordinate commander's after action report (AAR) might withhold information about a particular operation to alleviate scrutiny from the commanding officer. However, in a matrix structure, the commanding officer receives ammunition, supply replenishment, and intelligence reports recounting the overall operation. Analysis of these reports utilizing transparency shows inconsistencies in all operations, preventing malicious under-reporting.

Decision-makers must be willing to overcome the inertia that resists change within the organization and enable leaders to become change agents. Commanders must demolish the traditional hierarchical structure and break down the barriers of status, rank, and position in order to achieve greater subordinate aptitude. Despite the past successes of utilizing the hierarchical structure, the proposed matrix represents a model to capture inconsistencies. This increases the effectiveness and efficiency of the organizational planning by enhancing the knowledge base and SOP of the command hierarchy. Despite proposed organizational changes, the commander maintains the authority and responsibility of command.

B. ACHIEVING THE MATRIX

In order to achieve the matrix, the formal and informal cross-domain process workflows need to be documented. Once documented, these workflows can be analyzed and synthesized in order to determine the critical path(s) of dataflow. These synthesized data paths dictate the data that needs to flow from respective sensors to an appropriate decision point. The synthesized data paths link authoritative, un-altered data from the sensors to appropriate decision-makers. This alleviates the latency and potential for bias at each decision point within a hierarchical system flow.

1. Coarse-Grain Provenance

The most general approach to data flow, recording historical data sets, the human process interface, program interaction tracking, and sensor collection, is using analysis of the workflow coarse-grain provenance to derive the data fine-grain provenance. This form or provenance requires capturing the steps taken to achieve derivations, recording human interactions throughout the process(es), and tracking of external devices such as sensors, cameras, and other data collecting equipment (Islam, 2010). More specifically, coarse-grain provenance involves linking the decision-maker, or analyst, to the source data and illustrating how derived data has been calculated from raw observations (Islam, 2010). According to Islam (2010) a system records data sets from input, the tools used for processing, and the sequence of application steps during analysis. Ideally, workflow provenance allows users to find executable workflow process steps for each data item, but this causes complications for large data sets and requires additional techniques for querying data flow provenance.

2. Fine-Grain Provenance

Linking decision-makers directly to the source data will require the "authentication, integrity, and trustworthiness of the information (Islam, 2010, p. 1). According to Islam (2010), this type of authentication is known as "data provenance" (Islam, 2010, p. 1). Since the contents of databases are typically derived from other data sources such as the combination of other databases and/or user created data integration, provenance data describing creation, recording, ownership, processing, and version history is essential for judging quality and integrity of the data (Islam, 2010). Curated databases are created due to copying data from external sources or due to updating, inserting, or deleting data from the local database. The tracking of these actions is crucial in maintaining the provenance of data and can be done with the addition of a provenance store database and a local modification database. There must be a bi-directional feedback from the fine-grain dataflow into the coarse-grain workflow in order to achieve optimal states of data provenance.

C. MERGING WORKFLOWS

Step one in achieving an integrated information matrix is to document the physical process workflows of the organization. Once documented, the process workflows can be analyzed in order to determine where workflow merges would benefit the system. A workflow merge is defined as the process of combining one workflow schema into another, removing redundancies, and keeping all necessary steps to ensure context (Sun, Kumar, & Yen, 2006). After the formal and informal workflows are documented, a systemic approach is undertaken to eliminate redundant steps. A workflow merge is depicted in Figure 18. In this case, the workflows of Company A and Company B are merged; eliminating the redundancies (create order, create delivery), and necessary steps are retained (check credit, check availability, check payment, check stock).

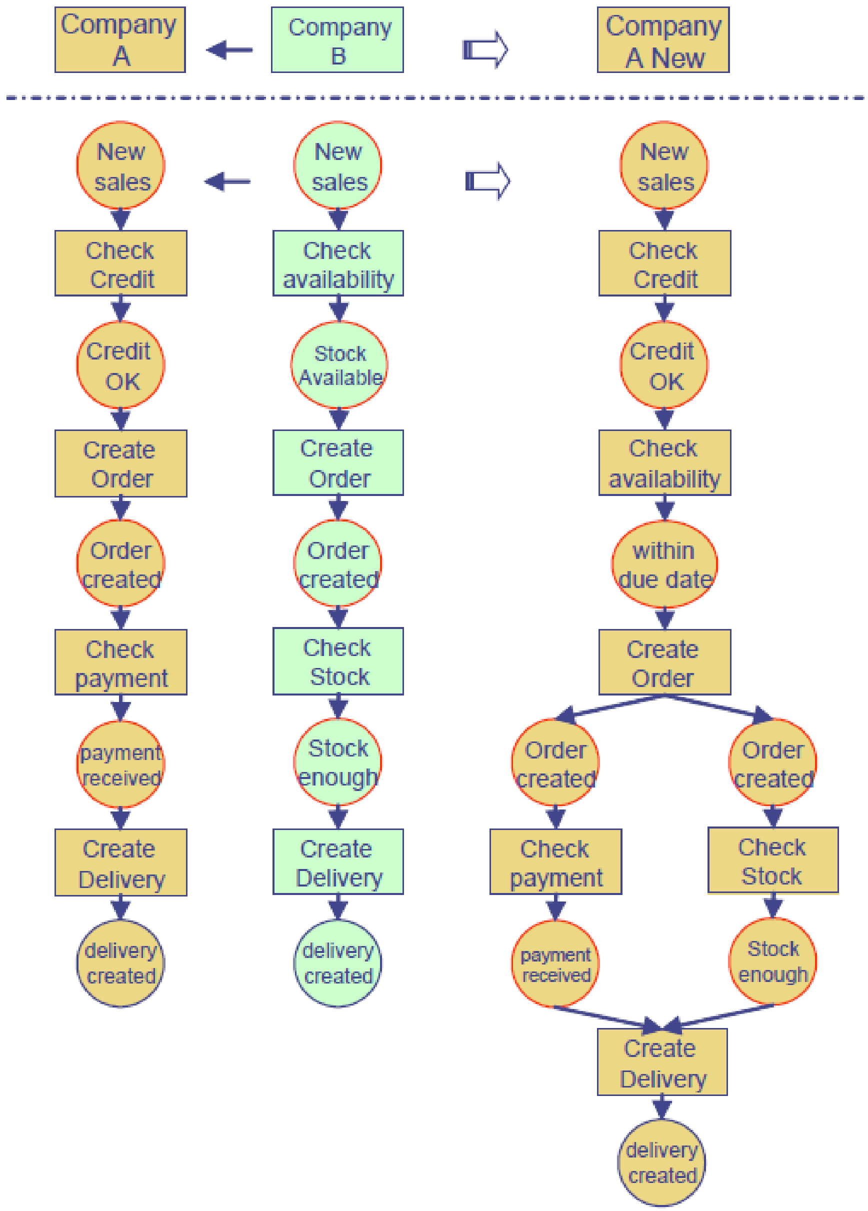

Figure 18. Complex Merge Scenario (from Sun, Kumar, & Yen, 2006)

When merging workflows, the first step is identifying merge points (Sun, Kumar, &Yen, 2006). Figure 18 depicts merge points identified as *create order* and *create delivery*. After the workflows are merged the result offers many benefits to the organization. These benefits include increased throughput, reliability, flexibility, and quality (Sun, Kumar, &Yen, 2006). Furthermore, the systematic approach and modeling of workflows allow the organization to perform simulations on newly designed workflows in order to achieve even higher states of effectiveness and efficiency.

The systematic modeling of the process workflows will identify areas where parallel functional areas possess merge points. However, parallel processes may have workflows that lend themselves to different types of merges. According to Sun, Kumar, and Yen (2006), there are four different types of merges, which combine workflows into more complex structured workflows (p. 854–855):

- "Concatenate, insert, replace: Two workflows are merged by concatenation or insertion, or a structured workflow is replaced by another structured workflow, resulting a change in the base workflow."
- "Parallel merge: Two structured workflows are combined in parallel using AND-SPLIT and AND-JOIN, resulting in process steps conducted in parallel by resulting in the same workflow outcome."
- "Conditional merge: Two structured workflows are combined in parallel using OR-SPLIT and OR-JOIN, resulting in a more efficient workflow."
- "Iterative merge: Variation of a conditional merge in which the OR-JOIN occurs first and it is followed by a matching OR-SPLIT. Since the original workflows are structures, the resultant workflow is also structured."

D. DECISION SUPPORT SYSTEM

In order to properly track and record provenance data, a data store (DS) must be created that ingests all layers of meta-data and data. Each meta-data entity is associated with each data occurrence within the DS. Meta-data and data ingested into the DS keeps organizational dataflows separated. Therefore meta-data and data views collected from C2, ISR, and Logistics workflows, need to be kept separate in order to maintain a high degree of fine-grain dataflow provenance. If this data from separate authoritative sources is allowed to migrate into a shared database structure, the source is no longer attributed as an authoritative source any longer. In addition, the authoritative sources granularity could be reduced. Once this data is ingested, it will be necessary to disseminate and manage the dataflow provenance. Due to the large amount of data that will be ingested, a policy reflecting the amount of dataflow provenance, and history, should be promulgated to minimize data store size.

Depicted in Figure 19, information is then extracted from the separate DSs and integrated into a single KB. Located within the KB there are staging and OLAP-friendly views for processing. The fusion engine operates over the staging views and generates fused views. These views are transformable by the users by applying OLAP aggregation/summarization operators as part of user decision-making activities during the OLAP Cube exploitation. Figure 19 represents ideal data integration scenario for the decision-maker describing end-to-end dataflow from the *authoritative data sources* directly to the user to realize D2D. The visualizations of the DSS analyze and interpret patterns or anomalies to increase the decision maker's perception. Additionally, predictive what-if scenarios are possible further improving the interactivity of the HCI.

Once this architectural data model is constructed, it can be built into a decision support system. Using knowledge visualizations, dataflows are linked to formal and informal workflows executed decision-makers. Feeding authoritative data sources into the appropriate fusion decision points overcomes the inefficiencies of the decision points of the command hierarchal structure. The proposed matrix enables D2D by yielding workflow and dataflow provenance efficiencies resulting in a superior degree of D2D.

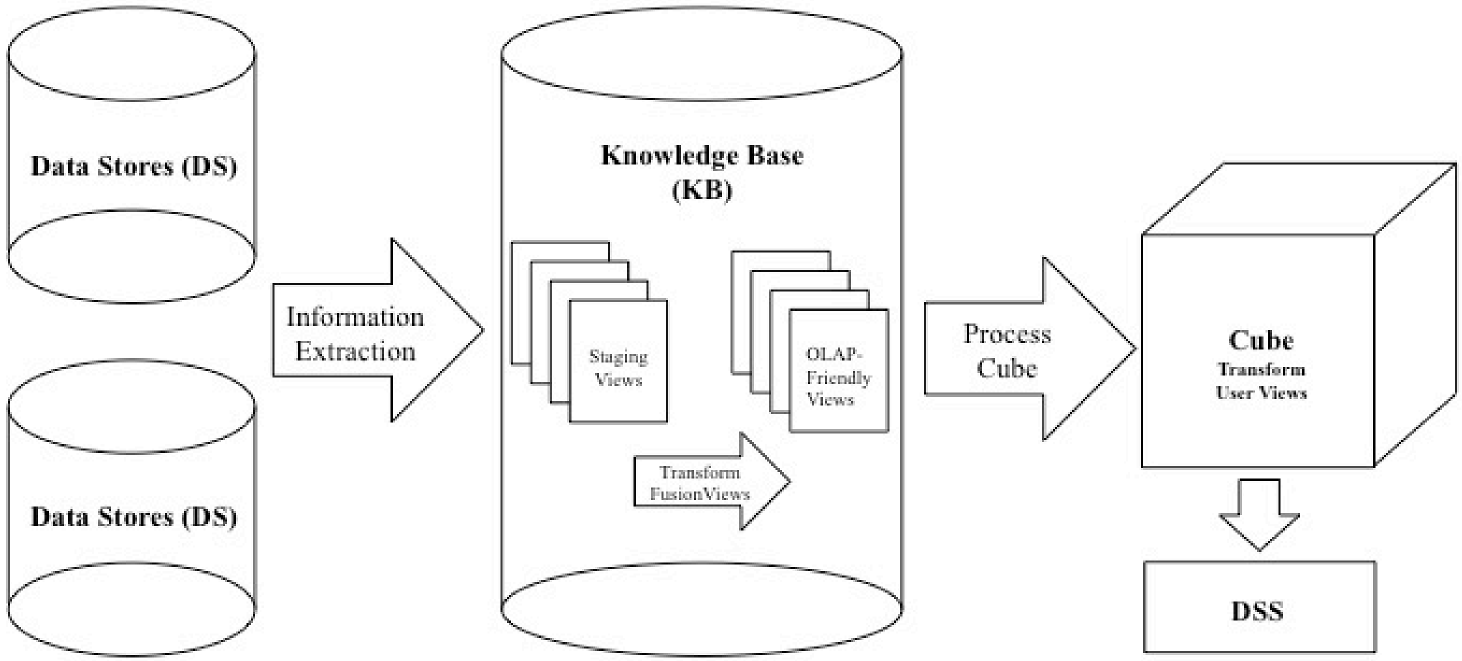

Figure 19. Data Integration

E. THE COGNITIVE MODEL OF THE MATRIX

Once in use, data can be collected and analyzed to identify focal points for increased efficiencies. Islam (2010) referred to this as fine-grain analysis or dataflow provenance, which is the information describing how data has moved through a network of databases. After enough provenance data has been collected, the DWM can be elevated from empirical and diagnostic, to a DWM with predictive and prescriptive capabilities. As depicted in Figure 20, the DWM gains cognitive power by composing elementary ideas into composite ideas that aid the decision-maker.

Adding cognitive capabilities to the DWM results in a DSS that visualizes the interpreted sensor information. The DWM is also in the position to prescribe its own FFIRs and PIRs organically, as well as alerting the decision-maker operating the DSS when the dynamic environment shifts outside the cognitive bounds of the decision-maker's SA.

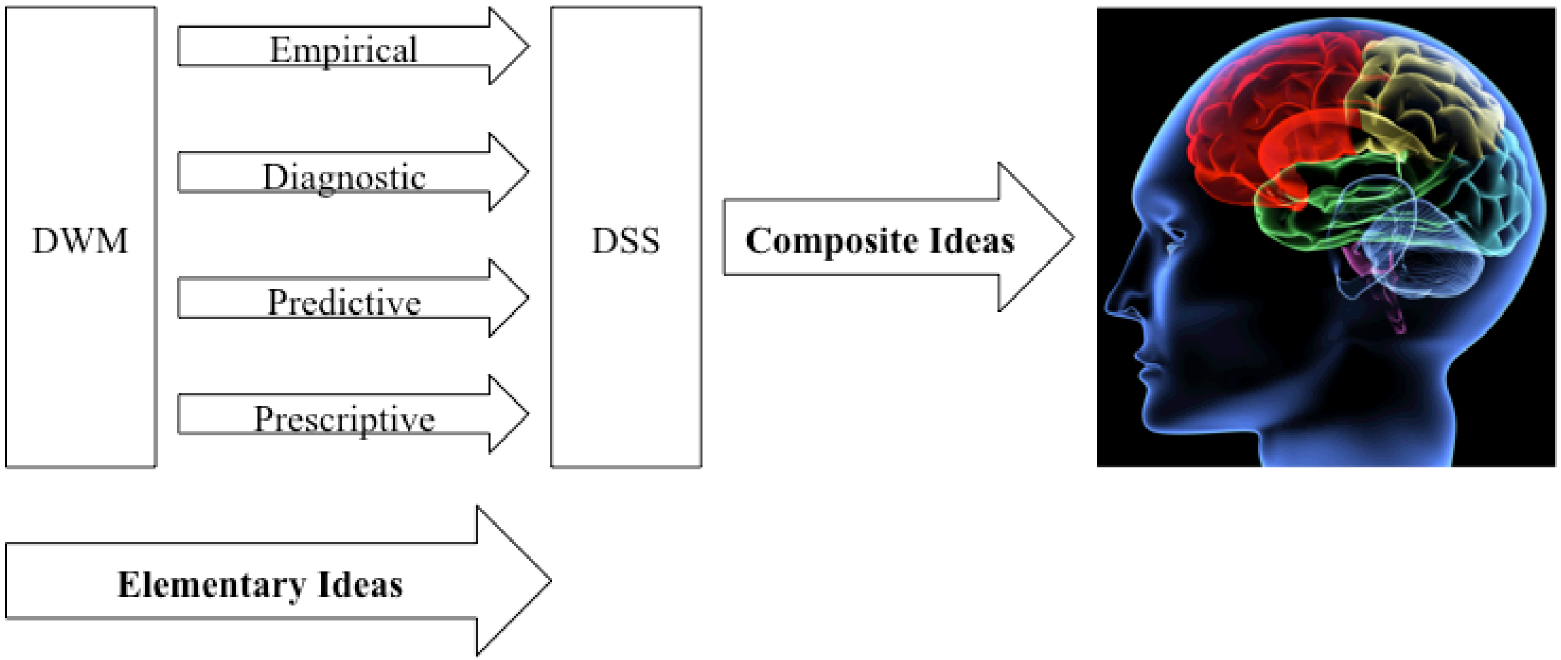

Figure 20. Cognitive Model of the Matrix (after “Concussions Accelerate Cognitive Decline,” 2012)

F. CONCLUSIONS

This research and analysis offers several conclusions regarding knowledge visualization techniques, which achieve optimized operational decision making and data integration, particularly with regard to information requirements, flow, and lineage.

Chapter three analyzes and breaks down the information requirements necessary for thorough COA analysis and selection for decision-makers taking into account risk analysis. Examination of the current doctrine and lessons learned from recent experiences lead to the compilation of the appropriate information requirements for operations, intelligence, and logistics functions of warfare planning and execution. Future IS applications requirements must ensure these and future determined information requests are included in the data query techniques.

The analysis establishes the importance of a matrix type organizational structure for informational flow. All nodes within the matrix must possess the ability to communicate with every other node within the matrix to ensure a common shared operation picture (SOP). This type of organizational structure ensures that the information relevant for decision-makers is available with limited latency and error induction. Eliminating the high number of decision points of the current (as-is) USMC hierarchal command structure of acquiring SA mitigates inefficiencies. Determining the critical paths for dataflow ensures that the required data reaches the appropriate automated and manual modes. Therefore, our research significantly contributes to the D2D challenge. This architecture is leveraged on ensuring coarse-grain workflow and fine-grain dataflow provenance. Increasing the veracity and velocity of information provides the decision-maker with a competitive advantage over the adversary, placing the commander within the OODA loop of the opposition.

The research found that a HCI dataflow model, taking advantage of the dataflow between the DWM and CWM, increases SA by improving understanding and wisdom. Those models interact by sharing conceptual relationships between the knowledge base, digital assistant, and cognitive assistant. The overall goal of enhanced SA based on the SOP is achievable by developing architectures based around the suggested dataflow model. In order to achieve the to-be integrated matrix, the SOP needs to be based on a sharable data model. The research, due to the ability to support command and other hierarchies, identified that this shareable data model requires OLAP cube data modeling.

The proposed data integration model ensures that authoritative sources of data from C2, ISR, and Logistics dataflows are kept separate to ensure dataflow provenance. Maintaining separate ingests into independent data stores ensures authenticity. Then the dataflow is assimilated into a single knowledge base where the fusion decision points create user transformable views from staging views within the knowledge base. This concept limits the hierarchal decision points and maximizes workflow and dataflow provenance minimizing the potential for errors and latency.

G. SUGGESTIONS FOR FURTHER RESEARCH

During the course of research and analysis several opportunities surfaced that are ideal for future explorations of these topics, but were left out due to the scope and time constraints of this project. These opportunities are outlined below.

The information requirements conceptualized through this research were based upon service specific dogma and lessons learned documentation, which often becomes doctrine. Deeper analysis is achievable through interview discovery of previous MAGTF Commanding Officers and their staffs in order to drill down further into the decision maker's information requirements for assessment and selection of COA alternatives. Incorporating commonalities of interviews or survey answers provides correlation analysis opportunities. These types of interviews and surveys create value for upgrades within the information collection algorithms of future system upgrades.

Additionally, organizational culture and psychological safety analysis of the baseline Marine Expeditionary Unit (MEU) is a beneficial analysis tool to determine how and where the MEU hierarchical structure must deemphasize status and rank to ensure success. Within the Marine Corps, the hierarchical structure, rank, and status of position mean a great deal with regard to authority and responsibility. Determining the probability of breaking down these barriers of hierarchical status is important in establishing opportunities for future success in creating the to-be matrix of information organizational sharing proposed within the research.

Future research is also recommended to identify workflow merge points across the warfighting domains of the ACE, GCE, and CSSE. Incorporating mergers of the process workflows at these points ensures the integration of C2ISR and Logistics functions. Integration of workflows helps decision-makers gain insights into optimizing processes, leading to increases in throughput, reductions in supply stockpiles, and ultimately increasing the value-chain across the warfighting domains.

Lastly, designing an application prototype of the to-be integrated matrix is the next, essential, step towards implementation of the proposed design. Follow on developmental testing of the prototypes is essential for satisfying the requirements analysis of the IS. This developmental testing conducted in coordination with operational evaluation testing of Marine Expeditionary Units provides operators with the ideal environment for critical analysis of the system’s capabilities and limitations. Further analysis of the application prototype limitations by decision-makers leads to the generation of creative solutions for future DSS software versions.

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